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EXECUTIVE SUMMARY

PICKERING NGS UNIT 1 MODERATOR DISTRIBUTION HEADER - RESULTS OF PRESSURE, FORCE/MOMENT AND RESIDUAL STRESS MEASUREMENTS

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Structural tests were performed on a removed moderator distribution header from Pickering NGS Unit 1. The purpose of these tests was to demonstrate the integrity of the header design (which is identical to the design of existing headers on Units 2,3 and 4). These tests were also to bench mark computer codes which were used to predict header behaviour for the test conditions.

Results from the pressure tests showed that the combination of header design and material selection was excellent in that the header was able to withstand a hydrostatic pressure of over 460 psi without failure (which is over three times design pressure). It was also demonstrated that the header would readily be able to sustain many cycles of pressure pulsation between 0 psi and 150 psi.

JC

job	file	date	report no.
21-186-451	825.22	August 19, 1987	87-128-K

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To Mr. W.F. McEwan
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PICKERING NGS UNIT 1 MODERATOR DISTRIBUTION HEADER
- RESULTS OF PRESSURE, FORCE/MOMENT AND RESIDUAL
STRESS MEASUREMENTS

1.0 INTRODUCTION

Moderator distribution headers of identical design were originally installed on Units 1 to 4 at Pickering NGS. Due to the subsequent incorporation of Emergency Core Injection Systems on these units, these headers (which became a critical part of the ECI systems) were subject to a re-analysis regarding their structural integrity.

The results of the theoretical re-analysis procedure indicated that stronger headers would be desirable. As such, replacement headers of a new more robust design were installed on Unit 1 during the extended outage on Units 1 and 2 required by the large scale fuel channel replacement program. (Replacement of the header for Unit 2 is presently underway).

Due to the expense that would be incurred if Units 3 and 4 were shut down specifically for header replacement, an effort was made to demonstrate that the existing headers on these units would be acceptable for continued service - at least for a period of time until a more convenient planned outage was available.

The removed header from Unit 1 provided an excellent opportunity to experimentally qualify the structural integrity of the existing headers on Units 3 and 4. (In addition, an experimental measurement program would provide basis for comparison between experimental results and those predicted by the computer codes which were used in the theoretical re-analysis procedure.)

A request[1] to the Experimental Stress Analysis Unit of Mechanical Research to perform an experimental investigation on a removed distribution header was made by the Mechanical Design Department, in co-operation with Pickering Engineering.

2.0 OBJECTIVE

This report discusses and documents the experimental program and the measurement results from a removed moderator distribution header from Pickering NGS Unit 1. Also covered are the implications of these tests regarding the structural integrity of the moderator distribution headers of Units 3 and 4 for normal and extreme operating conditions. The objective of this undertaking was to demonstrate the adequacy of the original header design for continuing service on Units 3 and 4, until such time as more robust headers could be installed.

3.0 BRIEF DESCRIPTION OF THE TEST PROCEDURES

The removed header from Unit 1 was relocated to the Auxiliary Irradiated Fuel Bay (AIFB) for the required tests. There, it was supported on the concrete floor and the end of the 16" diameter nozzle was affixed to a massive structural steel support column (as shown in Figure 1).

Three separate series of tests were performed.

i) Residual Stress Measurements

At a number of locations, particularly at juncture weld areas but also on the main body of the header, surface residual stress measurements were performed by the hole drilling method (as shown in Figure 2). After the pressure tests (described under item iii) were completed, a final set of residual stress measurements was performed.

ii) Force and Moment Tests

By means of turnbuckles, chain winches, and hydraulic cylinders, and employing the wall, support column or floor of the AIFB, forces in all three planes were imposed on the ends of the 10" and 6" diameter nozzles which were attached to the header. Shown in Figures 3, 4 and 5 are photographs of the tests for the forces: in the axial direction (relative to the 10" and 6" diameter nozzle axes); the vertical direction; and in the direction normal to the axial and vertical directions (ie, parallel to the axis of the main header).

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1 Memo from W.F. McEwan to Mr.T. Flaman, March 16, 1987, File No. NA44-32110 T4.

iii) Pressure Tests

For the final type of tests, the header was filled with water and hydrostatically pressurized. At various pressure levels, readings from the attached instrumentation were obtained. Figures 6, 7 and 8 illustrate details of the hydrostatic test procedures.

For the tests, the measurement devices included load cells, a pressure transducer, an electronic displacement transducer, thermocouples, and over 150 strain gauges bonded to critical locations on the outside surface of the structure. By means of long instrumentation wires, measurements were remotely recorded in a protected area by a computer controlled fast cycle data acquisition system, as shown in Figures 9 and 10.

4.0 TEST RESULTS AND DISCUSSION

Only selected results of the pressure tests are described in this section. Additional results of the pressure tests are listed in Appendix A. The results of the residual stress measurements and the force and moment tests are located in Appendix B and Appendix C, respectively.

4.1 Initial Pressurization to 150 psi

Listed on the next page, in Table 1, are selected results of the initial pressurization of the header from 0 psi to 150 psi and then back to 0 psi. Listed in this table are the data at 50 psi increments.

As an aid in understanding the data in Table 1, note that the 304 stainless steel of the header would have an initial yield stress of less than 50,000 psi: however, the calculation of stress in this experimental project simply assumed a perfectly linear stress/strain behaviour for all strain measurements. Therefore, measurement indications of stress in Table 1 that exceed yield (such as at the 150 psi pressure level) would simply indicate a condition of stress which was at or exceeding the yield stress. This calculation procedure was followed so that direct comparisons could be made between the experimental results and the numerical predictions (where the same assumptions were made regarding a completely linear stress/strain relationship). In addition, it is not usually possible to detect with certainty the onset or degree of yielding during such tests unless the behaviour of the material in the plastic condition is precisely known.

However, during pressurization material yielding (ie, assumed for this specific test as a stress magnitude over 50,000 psi) is first indicated to occur at about the 100 psi level (recorded in Data Record #121). Additional yielding is seen to occur at the 150 psi level where stresses at the flat area of the 16" diameter nozzle exceed 80,000 psi.

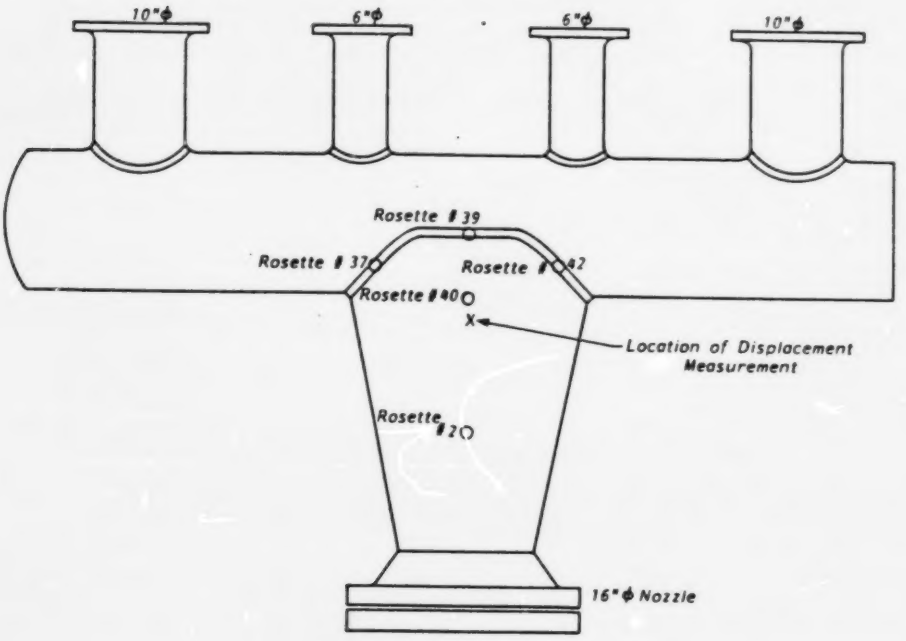
TABLE 1

Results of Initial Pressurization of Header: 0 psi - 150 psi - 0 psi

Data Record Number	Internal Pressure	Displacement	Rosette #2	Rosette #40	Rosette #37	Rosette #39	Rosette #42
	(PSI)	(Inches)	σ_1/σ_2	σ_1/σ_2	σ_1/σ_2	σ_1/σ_2	σ_1/σ_2
114	.0	0.007	0/0	0/0	0/0	0/0	0/0
117	50.7	0.344	31,000/12,700	30,500/23,600	19,000/6,000	4,980/-6,310	1,400/-1,500
121	99.5	0.614	53,450/21,100	56,150/44,600	38,310/5,460	9,590/-14,500	2,250/-3,020
126	148.7	0.893	81,030/33,400	80,670/65,450	55,800/-31.7	10,900/-26,520	2,330/-5,440
130	101.2	0.699	62,680/25,100	67,170/53,220	42,820/-3,840	6,590/-21,200	970/-4,650
133	50.7	0.448	37,580/14,100	48,040/36,900	27,350/-7,630	2,040/-14,800	-290/-3,420
135	.4	0.099	9,010/5,530	15,800/12,200	8,210/-12,000	-140/-6,120	-1,100/1,700

Notes:

1. Listed pressure readings are as recorded from the electronic pressure transducer.
2. Displacement is the total vertical displacement of the top surface of the 16" diameter nozzle relative to the bottom surface at a location marked by an "x" shown below on the diagram.
3. The stresses listed, σ_1/σ_2, are the principal stresses; ie, the maximum and minimum stress magnitudes in the plane of the strain gauge rosette.
4. Selected data for this test for the smaller nozzles are listed in Table A1, in Appendix A.



A more realistic indication that yielding may have occurred can be determined by noting the amount of apparent permanent deformation at the end of the pressurization cycle, where the header pressure has returned to 0 psi. (This is shown as Data Record #135 in Table 1.)

Permanent deformation and yielding is apparently confirmed at the 0 psi pressure level at the completion of this test. At this level, remaining stresses at certain locations are shown to be up to approximately 16,000 psi.

It must be noted that in describing the behaviour of structures under yielding or plastic conditions, particularly with regard to integrity, it is illustrative to study the strains as well as the stresses (especially in this case where unrealistic assumptions on linearity were made regarding stress/strain behaviour in the plastic regime).

For example, the net apparent permanent strain on this header that was evident when the pressure returned to 0 psi from the 150 psi pressure level was quite small. Permanent strains at and on the 16" diameter nozzle ranged from about -100 με to +400 με.[2]

This magnitude of strain deformation is extremely small compared to the ultimate strain capability of this material which is about 400,000 με (ie, 40%). Therefore, this material has a very large margin of plasticity (ie, a large ultimate strain range) in which to accommodate a realignment of component shape or local geometric discontinuities in order to effect "shakedown". This phenomenon is investigated in the next series of tests.

4.2 Pressure Cycling Between 0 psi and 150 psi

It would not be unexpected that the initial pressurization in these tests of this pressure vessel structure might result in some material yielding. This is particularly relevant considering the "damage" that may have occurred during the handling of the structure during its removal from Unit 1 and it's reassembly at the test location.

However, due to the phenomenon of material work hardening and due to a redistribution or amelioration of the stress pattern which likely would have occurred during the previous pressurization cycle from 0 psi to 150 psi, it would be expected that subsequent pressure cycling to 150 psi might result in the development of a stable (ie, non-yielding) structural behaviour. (This is particularly true considering the relatively small amount of yielding that was indicated to occur during the initial pressurization cycle.)

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[2] Strain is expressed a με (micro-strain) where 1,000 με is equivalent to a strain of 0.001 in/in or about 0.1%. Positive strains/stresses indicate a tensile condition.

TABLE 2

Results of Repetitive Pressure Cycling
0 psi - 150 psi - 0 psi

Data Record Number	Internal Pressure (PSI)	Displacement (Inches)	Rosette #2 σ_1/σ_2	Rosette #40 σ_1/σ_2	Rosette #37 σ_1/σ_2	Rosette #39 σ_1/σ_2	Rosette #42 σ_1/σ_2
113	0	0	0/0	0/0	0/0	0/0	0/0
126	148.7	0.893	81,030/33,400	80,670/65,450	55,800/-31.7	10,900/-26,520	2,330/-5,440
135	.4	0.098	9,010/5,530	15,800/12,200	8,210/-12,000	-140/-6,120	-1,100/-1,700
138	0	0	0/0	0/0	0/0	0/0	0/0
140	149.2	0.807	74,420/29,400	65,620/53,890	47,820/11,000	11,500/-21,400	3,600/-4,110
141	-.2	0.065	1,500/740	1,400/1,000	130/-1,000	-200/-640	-100/-100
142	0	0	0/0	0/0	0/0	0/0	0/0
143	151.2	0.754	78,380/32,400	65,200/53,700	48,260/12,000	11,900/-21,400	3,680/-4,100
144	-.2	0.062	1,600/1,000	640/400	40/-420	-60/-320	-100/-200
145	0	[5]	0/0	0/0	0/0	0/0	0/0
146	149.3		80,130/33,900	64,320/53,050	47,750/12,000	12,000/-21,000	3,670/-4,030
147	.0		300/200	300/200	100/-50	-.6/-200	0/-70
148	0	0	0/0	0/0	0/0	0/0	0/0
149	149.1	0.819	73,360/28,900[6]	64,240/53,010	47,680/12,000	12,000/-21,000	3,700/-4,020
150	-.1	0.004	-2,800/-3,990[6]	200/100	50/-10	20/-100	0/-40

Notes:

1. Listed pressure readings are as recorded from the electronic pressure transducer.

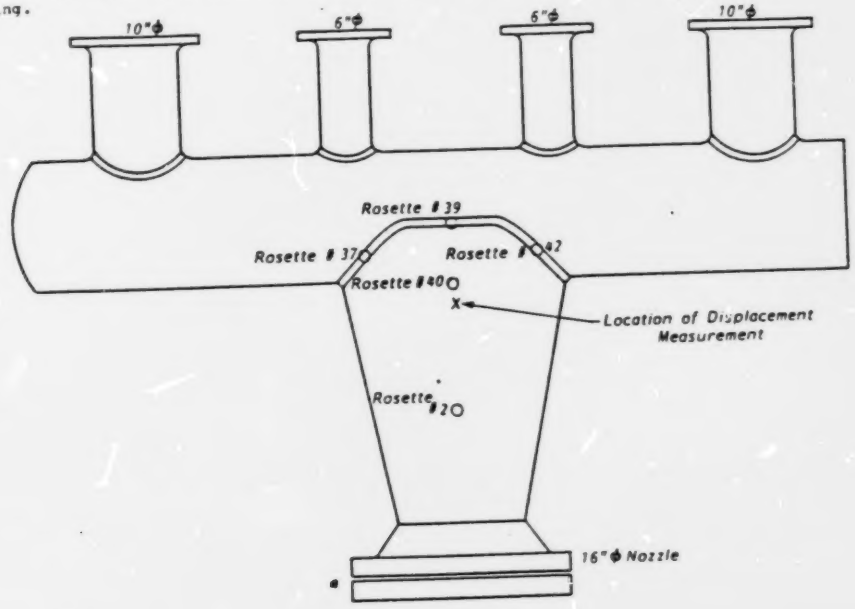
2. Displacement is the total vertical displacement of the top surface of the 16" diameter nozzle relative to the bottom surface at a location marked by an "x" shown below on the diagram.

3. The stresses listed, σ_1/σ_2, are the principal stresses; ie, the maximum and minimum stress magnitudes in the plane of the strain gauge rosette.

4. Selected data for this test for the smaller nozzles are listed in Table A2, in Appendix A.

5. Temporary failure of displacement transducer.

6. Rosette #2, for both principal stresses reads surprisingly low for data record #149 and for data record #150. Considering the indicated change to compressive stresses (ie, negative) at the return to zero pressure (data record #150), a momentary strain gauge failure, such as slippage, is possibly indicated for this reading.



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To investigate this, five full pressurization cycles to 150 psi pressure level (including the inital pressurization cycle) were performed: results are listed in Table 2. For each cycle, three sets of readings were recorded. At the beginning of each cycle at 0 psi internal pressure, all instruments were "zeroed"; at the maximum pressure of 150 psi a set of readings were taken; and at the return to 0 psi a set of (residual) readings were taken.

As can be seen in Table 2 , the structure appeared to stabilize after the third pressurization cycle. For the third, fourth and fifth cycles, stress readings at the 150 psi pressure level appear to have stabilized. This occurance indicates that these stress values are realistic (ie, the yield stress had increased due to the testing because the material is in the elastic range due to work hardening).

In addition, generally very small values of remaining stress are apparent at the completion of the third, fourth and fifth pressurization cycles. (These small recorded values are within the reading accuracy of the measurement equipment and therefore it is not possible to speculate whether even these small remaining deformations after depressurization even exist.) As such, this evidence of insignificant net deformation at the completion of the latter pressurization cycles further indicates that structural stabilization or shakedown has occurred.

4.3 Pressurization to Over 460 psi

To further obtain evidence of the structural capability of this header design, it was decided to pressurize to a level well above the design pressure of 150 psi.

For the final test, the structure was pressurized in complete cycles to increasing maximum pressure levels. This was first done in 50 psi increments between 150 psi and 300 psi (ie, - 0 psi - 150 psi - 0 psi, 0 psi - 200 psi - 0 psi, etc). Finally, it was decided to pressurize to a level of over 450 psi which would be in excess of three times the design level.

Full results of this series of tests are listed in Table 3 where it can be seen that readings were obtained at a test pressure of over 460 psi internal pressure. There was no evidence of leakage or imminent failure at this level.

However, a decision was made to terminate the tests at this point because it was felt that sufficient evidence had been obtained to fully demonstrate ample margins of safety for this header design. Also, there was a concern that the air and surfaces of the AIFB would be unnecessarily contaminated if pressurization was simply continued to higher levels until a

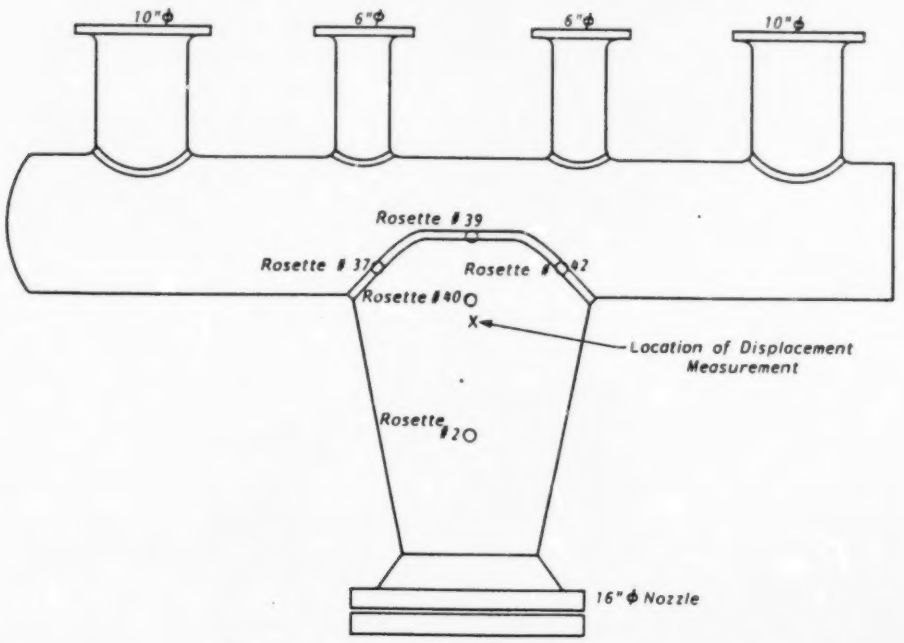
TABLE 3

Pressurization of Header to Over 450 psi

Data Record Number	Internal Pressure (PSI)	Displacement (Inches)	Rosette #2 σ_1/σ_2	Rosette #40 σ_1/σ_2	Rosette #37 σ_1/σ_2	Rosette #39 σ_1/σ_2	Rosette #42 σ_1/σ_2
114	0	0	0/0	0/0	0/0	0/0	0/0
126	148.7	0.893	81,030/33,400	80,670/65,450	55,800/-31.7	10,900/-26,520	2,330/-5,440
135	.4	0.099	9,010/5,530	15,800/12,200	8,210/-12,000	-140/-6,120	-1,100/-1,700
151	0	0	0/0	0/0	0/0	0/0	0/0
152	201.9	1.200	125,800/49,800	92,290/79,260	71,440/11,900	7,890/-37,170	3,450/-8,490
153	.1	0.220	28,600/8,000	23,000/17,000	12,000/-1,170	-3,100/-11,800	-1,000/-3,650
154	0	0	0/0	0/0	0/0	0/0	0/0
155	255.5	1.381	156,600/63,200	101,500/90,540	122,000/18,000	10,400/-40,900	11,400/-13,600
156	-.2	0.319	51,030/16,000	32,500/23,200	52,650/4,600	-3,300/-12,600	4,610/-8,180
157	0	0	0/0	0/0	0/0	0/0	0/0
158	293.4	1.303	139,000/60,500	91,980/83,320	121,300/18,300	14,400/-34,430	16,800/-11,900
159	.0	0.241	36,930/14,000	22,400/15,200	47,790/4,490	-1,400/-6,220	8,040/-6,400
161	0	0	0/0	0/0	0/0	0/0	0/0
162	463.3	1.887	214,700/98,090	228,700/155,200	353,610/42,320	18,580/-32,050	111,600/-12,770
164	.0	1.003	114,500/43,500	150,900/89,460	264,000/25,820	-5,500/-14,900	91,580/-9,439

Notes:

1. Listed pressure readings are as recorded from the electronic pressure transducer.
2. Displacement is the total vertical displacement of the top surface of the 16" diameter nozzle relative to the bottom surface at a location marked by an "x" shown below on the diagram.
3. The stresses listed, σ_1/σ_2, are the principal stresses; ie, the maximum and minimum stress magnitudes in the plane of the strain gauge rosette.
4. Selected data for this test for the smaller nozzles are listed in Table A3, in Appendix A.



leak occured. (This concern was particularly relevant considering the questionable integrity of the welds between the smaller diameter nozzles and the header: these unqualified welds were performed solely for these tests during header reassembly.)

For these tests, it is clear that increased amounts of material yielding occur at each increase in pressure magnitude. This is fully to be expected.

The amount of permanent deformation (as indicated at the completion of each pressure cycle) increases at each increased pressure level. It is not clear, however, whether the header would exhibit decreasing amounts of deformation (ie, shakedown or stability) at any pressure level above 150 psi: no repetitive cycling tests were done at pressures above this level.

If the strain deformation at the end of each individual pressure cycle is compared to the strain capability of the material, it can be seen that even if shakedown did not occur, there is an indication that the header could still withstand many pressure cycles, even at 460 psi. This would be true even if no work hardening or stress redistribution occurred at the higher stress levels, because it would likely require a significant number of cumulative strains due to high pressure cycling to approach the material's ultimate strain limit.

5.0 CONCLUSIONS

Residual stress measurements and force and moment measurements were performed on a removed Unit 1 moderator distribution header to investigate the structural integrity of the original Pickering 'A' header design and to provide comparison data to bench mark predictions made by numerical procedures. No evidence of unexpected or undesirable component performance was detected by these measurements.

An extensive series of hydrostatic pressure tests, combined with stress/strain and displacement measurements, were then performed on the removed Unit 1 header to investigate its behaviour under normal and extreme conditions.

The results of these pressurization tests indicated:

i) The header exhibited safe, repeatable and predictable structural performance at pressures up to (and possibly exceeding) 150 psi.

ii) The header withstood an internal pressure of over 460 psi (in excess of three times design pressure) without leakage and there was no indication that bursting or leakage was imminent.

iii) Material yielding was detected to occur at various locations on the structure for each initial pressurization to levels greater than 100 psi. The maximum recorded yield strains were very small, even at the 460 psi internal pressure level, compared to the ultimate strain capability of the header material: the structure would likely be able to sustain many over-pressurization cycles at 460 psi or possibly higher.

6.0 ACKNOWLEDGMENT

Guidance and direction for these tests was greatly appreciated and provided by Dave Moffat of Pickering Engineering; station assistance from Wayne Pettis and Bruce Smith of Pickering Construction enabled these tests to be performed efficiently and under excellent conditions; and the advice and assistance of Steve Ray and Brian Mills of Mechanical Research in the measurements themselves is kindly acknowledged.

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APPENDIX A

Selected Results of Pressure Tests for Smaller Nozzles

TABLE A1

Selected Stress Results for Smaller Nozzles Due to Initial Pressurization 0 psi - 150 psi - 0 psi

Data Record Number	Internal Pressure	Rosette 11	Rosette 17	Rosette 25	Rosette 35	Rosette 28	Rosette 30
	(PSI)	σ_1/σ_2	σ_1/σ_2	σ_1/σ_2	σ_1/σ_2	σ_1/σ_2	σ_1/σ_2
114	.0	60/0	60/0	30/0	30/0	-100/-760	0/0
117	50.7	11,000/6,850	-4,190/-29,000	-4,090/-25,200	7,200/5,850	1,400/88	1,500/97
121	99.5	21,000/13,300	-6,200/-53,840	-3,700/-44,040	13,900/11,200	3,100/460	2,900/190
126	148.7	31,500/20,000	-6,680/-77,510	-882/-60,640	20,800/16,900	4,840/850	4,260/28
130	101.2	23,100/14,500	-5,220/-60,190	755/-45,460	14,700/12,000	3,480/460	3,200/200
133	50.7	13,400/8,240	-2,680/-37,120	3,410/-25,100	7,830/6,470	1,800/100	1,800/100
135	.4	2,300/1,300	1,660/-6,510	7,660/1,600	750/670	50/-580	300/20

Notes:

1. Listed pressure readings are as recorded from the electronic transducer.

3. The stresses listed, σ_1/σ_2, are the principal stresses; ie, the maximum and minimum stress magnitudes.

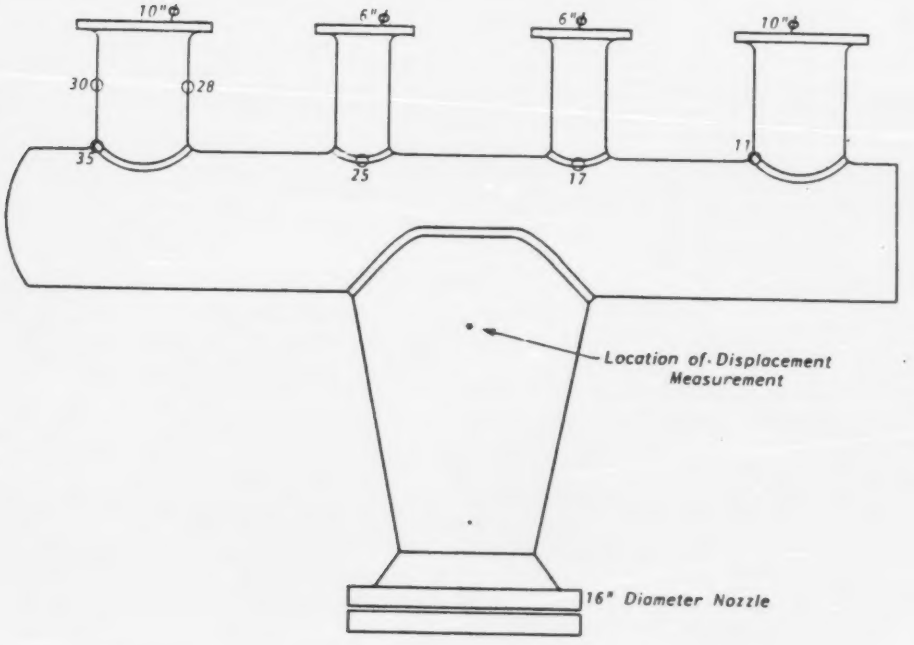


TABLE A2

Selected Stress Results for Smaller Nozzles Due to Repetitive Pressure Cycling 0 psi - 150 psi - 0 psi

Data Record Number	Internal Pressure	Rosette 11	Rosette 17	Rosette 25	Rosette 35	Rosette 28	Rosette 30
	(PSI)	σ_1/σ_2	σ_1/σ_2	σ_1/σ_2	σ_1/σ_2	σ_1/σ_2	σ_1/σ_2
113	0	0/0	0/0	0/0	0/0	0/0	0/0
126	148.7	31,500/20,000	-6,680/-77,510	-882/-60,640	20,800/16,900	4,840/850	4,260/2,800
135	.4	2,300/1,300	1,660/-6,510	7,660/1,600	750/670	50/-580	300/200
138	0	0/0	0/0	0/0	0/0	0/0	0/0
140	149.2	29,700/19,100	-8,050/-71,880	-8,090/-63,050	20,500/16,500	5,100/1,100	4,100/2,700
141	-.2	300/200	120/-650	180/-520	100/80	0/0	70/0
142	0	0/0	0/0	0/0	0/0	0/0	0/0
143	151.2	29,900/19,300	-8,110/-72,200	-8,080/63,210	20,600/16,700	5,160/1,100	4,100/2,700
144	-.2	100/100	100/-200	100/-100	50/-10	0/0	30/0
145	0	0/0	0/0	0/0	0/0	0/0	0/0
146	149.3	29,600/19,000	-8,090/-71,490	-8,010/-62,480	20,400/16,400	5,160/1,100	4,060/2,600
147	.0	100/80	50/-200	100/-40	30/0	0/0	70/0
148	0	0/0	0/0	0/0	0/0	0/0	0/0
149	149.1	29,700/19,100	-8,080/-71,430	-8,010/-62,400	20,500/16,500	5,080/1,100	4,100/2,700
150	-.1	300/200	50/-50	100/100	100/80	30/-30	0/0

Notes:

1. Listed pressure readings are as recorded from the electronic pressure transducer.

3. The stresses listed, σ_1/σ_2, are the principal stresses; ie, the maximum and minimum stress magnitudes.

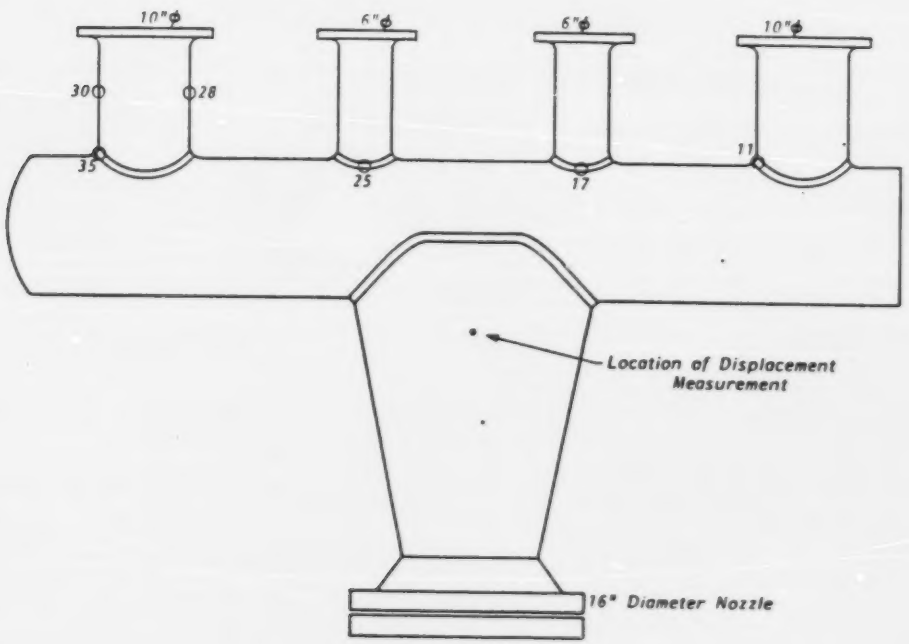


TABLE A3

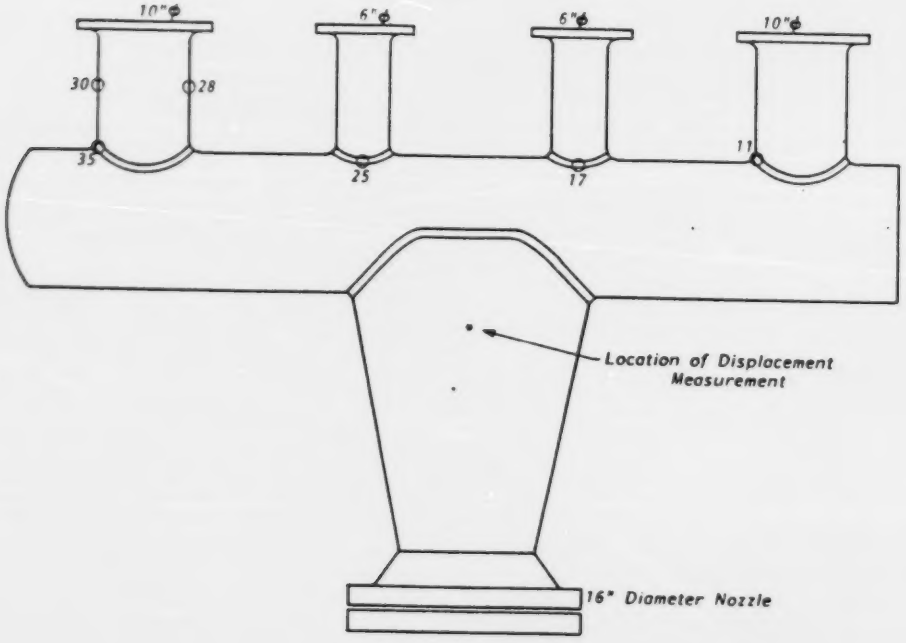
Selected Stress Results for Smaller Nozzles Due to Pressurization to over 450 psi

Data Record Number	Internal Pressure (PSI)	Rosette 11 σ_1/σ_2	Rosette 17 σ_1/σ_2	Rosette 25 σ_1/σ_2	Rosette 35 σ_1/σ_2	Rosette 28 σ_1/σ_2	Rosette 30 σ_1/σ_2
114	0	0/0	0/0	0/0	0/0	0/0	0/0
126	148.7	31,500/20,000	-6,680/-77,510	-882/-60,640	20,800/16,900	4,840/950	4,260/2,800
135	.4	2,300/1,300	1,660/-6,510	7,660/1,600	750/670	50/-580	300/200
151	0	0/0	0/0	0/0	0/0	0/0	0/0
152	201.9	41,220/27,200	-5,020/-97,170	-3,820/-81,460	28,100/23,000	7,060/1,500	5,530/3,700
153	.1	3,400/2,300	2,910/-13,300	3,930/-7,860	1,300/1,100	640/40	410/300
154	0	0/0	0/0	0/0	0/0	0/0	0/0
155	255.5	50,290/34,800	-1,869/-104,700	-,910/-90,300	35,900/29,300	8,390/2,100	6,550/4,600
156	-.2	5,550/4,000	3,950/-15,000	3,050/-11,500	2,700/1,900	960/100	510/400
157	0	0/0	0/0	0/0	0/0	0/0	0/0
158	293.4	54,120/37,700	-2,750/-100,300	-4,090/-87,740	40,210/32,600	8,620/2,000	6,940/5,040
159	.0	4,860/3,600	1,380/8,660	815/-7,030	2,700/1,500	280/-210	460/300
161	0	0/0	0/0	0/0	0/0	0/0	0/0
162	463.3	110,500/81,180	-863.7/-121,80	-3,240/-103,500	80,390/62,330	11,700/4,400	8,620/8,290
164	.0	45,080/30,100	-5,370/-34,370	-4,650/-26,700	26,000/122,200	2,200/360	1,600/400

Notes:

1. Listed pressure readings are as recorded from the electronic pressure transducer.

3. The stresses listed, σ_1/σ_2, are the principal stresses; ie, the maximum and minimum stress magnitudes.



APPENDIX B

Residual Stress Measurement Results

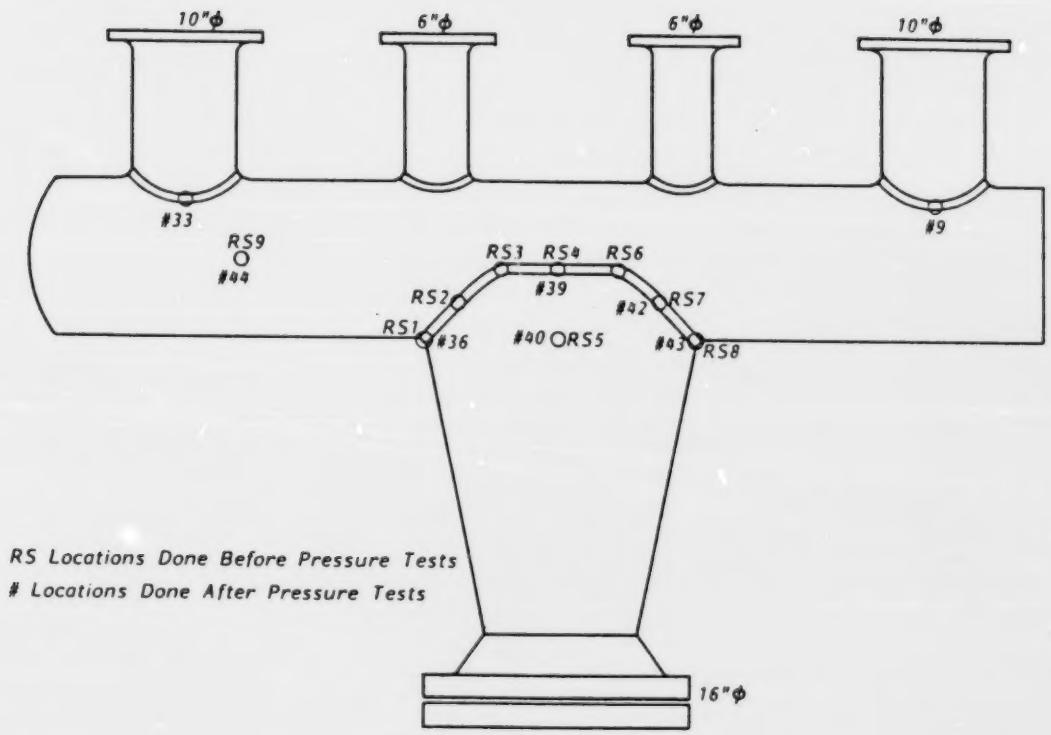


FIGURE B1
LOCATION OF RESIDUAL STRESS MEASUREMENTS
ON DISTRIBUTION HEADER

174905-RD

PICKERING MODERATER HEADER - RESIDUAL STRESS MEASUREMENTS

MEASUREMENT LOCATION:

LOCATION RS1 DATE: 13/04/87
(Refer to Figure 1) TIME: 10:25

ROSETTE TYPE:062-RE
YOUNG'S MODULUS: 30.0 Mpsi
POISSON'S RATIO:0.30
HOLE DEPTH INCREMENT:0.010in.
HOLE DIAMETER:0.063in.

PRINCIPAL STRESSES:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) SIGMA1	SIGMA2	PRINCIPAL ANGLE(DEG.)
0.000 - 0.010	+7	+12	+5	-1.4	-8.4	+130.0
0.010 - 0.020	+11	+18	+7	-.2	-1.6	+118.0
0.020 - 0.030	+14	+21	+9	-1.3	-2.3	+52.6
0.030 - 0.039	+51	+48	+13	-32.6	-66.6	+100.0
AVERAGES:				-8.9	-19.7	+100.2

1 R= 3.211211680S8

STRESSES IN GAGE DIRECTIONS:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) AXIAL	SHEAR	TRANS.
0.000 - 0.010	+7	+12	+5	-5.5	-3.4	-4.4
0.010 - 0.020	+11	+18	+7	-1.3	-.6	-.5
0.020 - 0.030	+14	+21	+9	-1.9	+.5	-1.7
0.030 - 0.039	+51	+48	+13	-65.6	-5.9	-33.6
AVERAGES:				-18.6	-2.4	-10.0

NOTES:

1) The 'AXIAL' gage is at 0 degrees;often called 'GAGE 1'.
2) The 'SHEAR' gage is at 45 degrees;often called 'GAGE 2'.
3) The 'TRANSVERSE' gage is at 90 degrees;often called 'GAGE 3'.
4) If any stress exceeds yield, all calculated stresses in deeper increments are not valid and must not be used.
5) Angles are measured +ve counter-clockwise from the 'AXIAL' gage.

PICKERING MODERATER HEADER - RESIDUAL STRESS MEASUREMENTS

MEASUREMENT LOCATION:

LOCATION RSZ
(Refer to Figure 1)

DATE: 09/04/87
TIME: 13:55

ROSETTE TYPE:062-RE
YOUNG'S MODULUS: 30.0 Mpsi
POISSON'S RATIO:0.30
HOLE DEPTH INCREMENT:0.010in.
HOLE DIAMETER:0.060in.

PRINCIPAL STRESSES:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) SIGMA1	SIGMA2	PRINCIPAL ANGLE(DEG.)
0.000 - 0.010	+15	-2	-4	+2.2	-10.4	+70.8
0.010 - 0.020	+24	-10	-37	+22.0	+2.0	+99.8
0.020 - 0.030	+26	-8	-73	+32.4	+3.1	+117.0
0.030 - 0.039	+26	-4	-100	+35.0	+6.5	+119.0
AVERAGES:				+22.9	+.3	+101.7

I R= 3.06185299776

STRESSES IN GAGE DIRECTIONS:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) AXIAL	SHEAR	TRANS.
0.000 - 0.010	+15	-2	-4	-9.0	+3.9	+.8
0.010 - 0.020	+24	-10	-37	+2.5	-3.4	+21.4
0.020 - 0.030	+26	-8	-73	+9.3	-12.0	+26.2
0.030 - 0.039	+26	-4	-100	+13.3	-12.2	+28.1
AVERAGES:				+4.0	-5.9	+19.1

NOTES:

1) The 'AXIAL' gage is at 0 degrees;often called 'GAGE 1'.
2) The 'SHEAR' gage is at 45 degrees;often called 'GAGE 2'.
3) The 'TRANSVERSE' gage is at 90 degrees;often called 'GAGE 3'.
4) If any stress exceeds yield, all calculated stresses in deeper increments are not valid and must not be used.
5) Angles are measured +ve counter-clockwise from the 'AXIAL' gage.

PICKERING MODERATER HEADER - RESIDUAL STRESS MEASUREMENTS

MEASUREMENT LOCATION:

LOCATION RS3 — DATE: 09/04/87
(Refer to Figure 1) — TIME: 11:42

ROSETTE TYPE:062-RE
YOUNG'S MODULUS: 30.0 Mpsi
POISSON'S RATIO:0.30
HOLE DEPTH INCREMENT:0.010in.
HOLE DIAMETER:0.062in.

PRINCIPAL STRESSES:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) SIGMA1	SIGMA2	PRINCIPAL ANGLE(DEG.)
0.000 - 0.010	-89	-85	-52	+62.0	+38.6	+19.1
0.010 - 0.020	-191	-154	-91	+51.1	+24.5	-7.5
0.020 - 0.030	-273	-201	-107	+45.3	+15.9	-2.3
0.030 - 0.039	-318	-223	-109	+26.4	+4.7	-4.0
AVERAGES:				+46.2	+20.9	+1.3

1 R= 2.99226542963

STRESSES IN GAGE DIRECTIONS:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) AXIAL	SHEAR	TRANS.
0.000 - 0.010	-89	-85	-52	+59.4	+7.2	+41.1
0.010 - 0.020	-191	-154	-91	+50.7	-3.4	+25.0
0.020 - 0.030	-273	-201	-107	+45.3	-1.2	+16.0
0.030 - 0.039	-318	-223	-109	+26.3	-1.5	+4.8
AVERAGES:				+45.4	+.3	+21.7

NOTES:

1) The 'AXIAL' gage is at 0 degrees;often called 'GAGE 1'.
2) The 'SHEAR' gage is at 45 degrees;often called 'GAGE 2'.
3) The 'TRANSVERSE' gage is at 90 degrees;often called 'GAGE 3'.
4) If any stress exceeds yield, all calculated stresses in deeper increments are not valid and must not be used.
5) Angles are measured +ve counter-clockwise from the 'AXIAL' gage.

PICKERING MODERATER HEADER - RESIDUAL STRESS MEASUREMENTS

MEASUREMENT LOCATION:

LOCATION RS4 — DATE: 09/04/87
(Refer to Figure 1) — TIME: 11:14

ROSETTE TYPE:062-RE
YOUNG'S MODULUS: 30.0 Mpsi
POISSON'S RATIO:0.30
HOLE DEPTH INCREMENT:0.010in.
HOLE DIAMETER:0.062in.

PRINCIPAL STRESSES:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) SIGMA1	SIGMA2	PRINCIPAL ANGLE(DEG.)
0.000 - 0.010	-68	-39	+3	+43.0	+5.5	+5.2
0.010 - 0.020	-162	-85	+4	+49.3	+11.3	-2.3
0.020 - 0.030	-259	-128	+28	+57.4	-2.4	+4.1
0.030 - 0.039	-318	-153	+55	+35.4	-14.7	+7.6
AVERAGES:				+46.3	-.1	+3.6

I R= 3.06185299776

STRESSES IN GAGE DIRECTIONS:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) AXIAL	SHEAR	TRANS.
0.000 - 0.010	-68	-39	+3	+42.7	+3.4	+5.8
0.010 - 0.020	-162	-85	+4	+49.3	-1.6	+11.3
0.020 - 0.030	-259	-128	+28	+57.1	+4.2	-2.1
0.030 - 0.039	-318	-153	+55	+34.5	+6.5	-13.8
AVERAGES:				+45.9	+3.2	+.3

NOTES:

1) The 'AXIAL' gage is at 0 degrees;often called 'GAGE 1'.
2) The 'SHEAR' gage is at 45 degrees;often called 'GAGE 2'.
3) The 'TRANSVERSE' gage is at 90 degrees;often called 'GAGE 3'.
4) If any stress exceeds yield, all calculated stresses in deeper increments are not valid and must not be used.
5) Angles are measured +ve counter-clockwise from the 'AXIAL' gage.

PICKERING MODERATER HEADER - RESIDUAL STRESS MEASUREMENTS

MEASUREMENT LOCATION:

LOCATION RS5 DATE: 09/04/87
(Refer to Figure 1) TIME: 10:45

ROSETTE TYPE:062-RE
YOUNG'S MODULUS: 30.0 Mpsi
POISSON'S RATIO:0.30
HOLE DEPTH INCREMENT:0.010in.
HOLE DIAMETER:0.062in.

PRINCIPAL STRESSES:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) SIGMA1	SIGMA2	PRINCIPAL ANGLE(DEG.)
0.000 - 0.010	+4	+17	+19	-3.8	-13.4	-18.2
0.010 - 0.020	+27	+47	+36	-8.7	-18.9	+118.0
0.020 - 0.030	+36	+59	+45	-3.4	-3.8	-35.4
0.030 - 0.039	+40	+63	+49	-.7	-3.0	+46.9
AVERAGES:				-4.1	-9.8	+27.8

1 R= 3.06185299776

STRESSES IN GAGE DIRECTIONS:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) AXIAL	SHEAR	TRANS.
0.000 - 0.010	+4	+17	+19	-4.7	-2.9	-12.5
0.010 - 0.020	+27	+47	+36	-16.6	-4.3	-10.9
0.020 - 0.030	+36	+59	+45	-3.5	-.2	-3.7
0.030 - 0.039	+40	+63	+49	-1.9	+1.2	-1.8
AVERAGES:				-6.7	-1.5	-7.2

NOTES:

1) The 'AXIAL' gage is at 0 degrees;often called 'GAGE 1'.
2) The 'SHEAR' gage is at 45 degrees;often called 'GAGE 2'.
3) The 'TRANSVERSE' gage is at 90 degrees;often called 'GAGE 3'.
4) If any stress exceeds yield, all calculated stresses in deeper increments are not valid and must not be used.
5) Angles are measured +ve counter-clockwise from the 'AXIAL' gage.

PICKERING MODERATER HEADER - RESIDUAL STRESS MEASUREMENTS

****

MEASUREMENT LOCATION:

LOCATION RS6 DATE: 09/04/87
(Refer to Figure 1) TIME: 12:05

ROSETTE TYPE:062-RE
YOUNG'S MODULUS: 30.0 Mpsi
POISSON'S RATIO:0.30
HOLE DEPTH INCREMENT:0.010in.
HOLE DIAMETER:0.062in.

PRINCIPAL STRESSES:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) SIGMA1	SIGMA2	PRINCIPAL ANGLE(DEG.)
0.000 - 0.010	-66	-24	-43	+57.6	+23.7	-34.7
0.010 - 0.020	-132	-33	-66	+38.7	+5.4	-27.9
0.020 - 0.030	-176	-25	-72	+28.1	-4.0	-29.5
0.030 - 0.039	-199	-15	-70	+15.0	-8.7	-28.7
AVERAGES:				+34.9	+4.1	-30.2

1 R= 3.06185299776

STRESSES IN GAGE DIRECTIONS:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) AXIAL	SHEAR	TRANS.
0.000 - 0.010	-66	-24	-43	+46.7	-15.9	+34.7
0.010 - 0.020	-132	-33	-66	+31.4	-13.7	+12.7
0.020 - 0.030	-176	-25	-72	+20.3	-13.7	+3.8
0.030 - 0.039	-199	-15	-70	+9.5	-10.0	-3.3
AVERAGES:				+27.0	-13.3	+12.0

NOTES:

1) The 'AXIAL' gage is at 0 degrees;often called 'GAGE 1'.
2) The 'SHEAR' gage is at 45 degrees;often called 'GAGE 2'.
3) The 'TRANSVERSE' gage is at 90 degrees;often called 'GAGE 3'.
4) If any stress exceeds yield, all calculated stresses in deeper increments are not valid and must not be used.
5) Angles are measured +ve counter-clockwise from the 'AXIAL' gage.

PICKERING MODERATER HEADER - RESIDUAL STRESS MEASUREMENTS

MEASUREMENT LOCATION:

LOCATION R57 DATE: 09/04/87
(Refer to Figure 1) TIME: 14:30

ROSETTE TYPE:062-RE
YOUNG'S MODULUS: 30.0 Mpsi
POISSON'S RATIO:0.30
HOLE DEPTH INCREMENT:0.010in.
HOLE DIAMETER:0.060in.

PRINCIPAL STRESSES:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) SIGMA1	SIGMA2	PRINCIPAL ANGLE(DEG.)
0.000 - 0.010	-21	-13	-21	+19.8	+11.5	-45.0
0.010 - 0.020	-70	-49	-54	+33.4	+24.5	-9.3
0.020 - 0.030	-99	-85	-66	+22.3	-1.9	+34.8
0.030 - 0.039	-118	-106	-67	+16.5	-2.7	+25.2
AVERAGES:				+23.0	+7.9	+1.4

1 R= 3.06185299776

STRESSES IN GAGE DIRECTIONS:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) AXIAL	SHEAR	TRANS.
0.000 - 0.010	-21	-13	-21	+15.7	-4.2	+15.7
0.010 - 0.020	-70	-49	-54	+33.2	-1.4	+24.8
0.020 - 0.030	-99	-85	-66	+14.4	+11.4	+6.0
0.030 - 0.039	-118	-106	-67	+13.1	+7.4	+.8
AVERAGES:				+19.1	+3.3	+11.8

NOTES:

1) The 'AXIAL' gage is at 0 degrees;often called 'GAGE 1'.
2) The 'SHEAR' gage is at 45 degrees;often called 'GAGE 2'.
3) The 'TRANSVERSE' gage is at 90 degrees;often called 'GAGE 3'.
4) If any stress exceeds yield, all calculated stresses in deeper increments are not valid and must not be used.
5) Angles are measured +ve counter-clockwise from the 'AXIAL' gage.

PICKERING MODERATER HEADER - RESIDUAL STRESS MEASUREMENTS
****

MEASUREMENT LOCATION:

LOCATION RS8 DATE: 13/04/87
(Refer to Figure 1) TIME: 10:55

ROSETTE TYPE:062-RE
YOUNG'S MODULUS: 30.0 Mpsi
POISSON'S RATIO:0.30
HOLE DEPTH INCREMENT:0.010in.
HOLE DIAMETER:0.063in.

PRINCIPAL STRESSES:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) SIGMA1	SIGMA2	PRINCIPAL ANGLE(DEG.)
0.000 - 0.010	+10	+4	-11	+6.6	-5.8	+102.0
0.010 - 0.020	-15	-21	-40	+25.0	+23.4	-12.3
0.020 - 0.030	-35	-42	-49	+16.2	+2.6	+23.7
0.030 - 0.039	-47	-59	-53	+16.5	+.4	+33.7
AVERAGES:				+16.1	+5.2	+36.8

i R= 3.13475425961

STRESSES IN GAGE DIRECTIONS:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) AXIAL	SHEAR	TRANS.
0.000 - 0.010	+10	+4	-11	-5.3	-2.5	+6.1
0.010 - 0.020	-15	-21	-40	+25.0	-.3	+23.4
0.020 - 0.030	-35	-42	-49	+14.1	+5.0	+4.8
0.030 - 0.039	-47	-59	-53	+11.6	+7.4	+5.4
AVERAGES:				+11.3	+2.4	+9.9

NOTES:

1) The 'AXIAL' gage is at 0 degrees;often called 'GAGE 1'.
2) The 'SHEAR' gage is at 45 degrees;often called 'GAGE 2'.
3) The 'TRANSVERSE' gage is at 90 degrees;often called 'GAGE 3'.
4) If any stress exceeds yield, all calculated stresses in deeper increments are not valid and must not be used.
5) Angles are measured +ve counter-clockwise from the 'AXIAL' gage.

PICKERING MODERATER HEADER - RESIDUAL STRESS MEASUREMENTS
****

MEASUREMENT LOCATION:

LOCATION RS9 DATE: 09/04/87
(Refer to Figure 1) TIME: 13:25

ROSETTE TYPE:062-RE
YOUNG'S MODULUS: 30.0 Mpsi
POISSON'S RATIO:0.30
HOLE DEPTH INCREMENT:0.010in.
HOLE DIAMETER:0.066in.

PRINCIPAL STRESSES:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) SIGMA1	SIGMA2	PRINCIPAL ANGLE(DEG.)
0.000 - 0.010	-1	-2	+2	+1.1	-1.9	+29.5
0.010 - 0.020	-6	-5	-1	+4.6	+2.6	-37.0
0.020 - 0.030	-48	-35	-15	+42.8	+25.0	+4.3
0.030 - 0.039	-80	-60	-24	+39.1	+22.3	+12.1
AVERAGES:				+21.9	+12.0	+2.2

1 R= 3.06185299776

STRESSES IN GAGE DIRECTIONS:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) AXIAL	SHEAR	TRANS.
0.000 - 0.010	-1	-2	+2	+.4	+1.3	-1.2
0.010 - 0.020	-6	-5	-1	+3.9	-1.0	+3.3
0.020 - 0.030	-48	-35	-15	+42.7	+1.3	+25.1
0.030 - 0.039	-80	-60	-24	+38.3	+3.4	+23.1
AVERAGES:				+21.3	+1.3	+12.6

NOTES:

1) The 'AXIAL' gage is at 0 degrees;often called 'GAGE 1'.
2) The 'SHEAR' gage is at 45 degrees;often called 'GAGE 2'.
3) The 'TRANSVERSE' gage is at 90 degrees;often called 'GAGE 3'.
4) If any stress exceeds yield, all calculated stresses in deeper increments are not valid and must not be used.
5) Angles are measured +ve counter-clockwise from the 'AXIAL' gage.

PICKERING MODERATER HEADER - RESIDUAL STRESS MEASUREMENTS

MEASUREMENT LOCATION:

LOCATION 40 - AFTER PROOF TESTING
(Refer to Figure 1)

DATE: 08/05/87
TIME: 10:20

ROSETTE TYPE:062-RE
YOUNG'S MODULUS: 30.0 Mpsi
POISSON'S RATIO:0.30
HOLE DEPTH INCREMENT:0.010in.
HOLE DIAMETER:0.066in.

PRINCIPAL STRESSES:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) SIGMA1	SIGMA2	PRINCIPAL ANGLE(DEG.)
0.000 - 0.010	-6	-5	-7	+5.7	+4.0	+126.0
0.010 - 0.020	-10	-9	-11	+1.7	+1.3	+34.6
0.020 - 0.030	-11	-12	-12	+.8	-2.0	+44.5
0.030 - 0.039	-13	-11	-13	+4.8	-.4	-39.9
AVERAGES:				+3.3	+.7	+41.3

1 R= 3.06185299776

STRESSES IN GAGE DIRECTIONS:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) AXIAL	SHEAR	TRANS.
0.000 - 0.010	-6	-5	-7	+4.6	-.8	+5.1
0.010 - 0.020	-10	-9	-11	+1.6	+.2	+1.4
0.020 - 0.030	-11	-12	-12	-.6	+1.4	-.6
0.030 - 0.039	-13	-11	-13	+2.6	-2.6	+1.7
AVERAGES:				+2.1	-.4	+1.9

NOTES:

1) The 'AXIAL' gage is at 0 degrees;often called 'GAGE 1'.
2) The 'SHEAR' gage is at 45 degrees;often called 'GAGE 2'.
3) The 'TRANSVERSE' gage is at 90 degrees;often called 'GAGE 3'.
4) If any stress exceeds yield, all calculated stresses in deeper increments are not valid and must not be used.
5) Angles are measured +ve counter-clockwise from the 'AXIAL' gage.

PICKERING MODERATER HEADER - RESIDUAL STRESS MEASUREMENTS

MEASUREMENT LOCATION:

LOCATION 39 - AFTER PROOF TESTING
(Refer to Figure 1)

DATE: 08/05/87
TIME: 10:48

ROSETTE TYPE:062-RE
YOUNG'S MODULUS: 30.0 Mpsi
POISSON'S RATIO:0.30
HOLE DEPTH INCREMENT:0.010in.
HOLE DIAMETER:0.063in.

PRINCIPAL STRESSES:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) SIGMA1	SIGMA2	PRINCIPAL ANGLE(DEG.)
0.000 - 0.010	-1	-5	+4	+2.8	-5.2	+34.5
0.010 - 0.020	-5	-17	+21	+5.4	-16.7	+29.7
0.020 - 0.030	-5	-36	+53	+3.6	-42.7	+33.1
0.030 - 0.039	-8	-61	+73	+15.1	-36.6	+36.6
AVERAGES:				+6.7	-25.3	+33.5

1 R= 3.21121168058

STRESSES IN GAGE DIRECTIONS:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) AXIAL	SHEAR	TRANS.
0.000 - 0.010	-1	-5	+4	+.2	+3.7	-2.7
0.010 - 0.020	-5	-17	+21	-.1	+9.5	-11.3
0.020 - 0.030	-5	-36	+53	-10.2	+21.2	-28.9
0.030 - 0.039	-8	-61	+73	-3.2	+24.8	-18.2
AVERAGES:				-3.3	+14.8	-15.3

NOTES:

1) The 'AXIAL' gage is at 0 degrees;often called 'GAGE 1'.
2) The 'SHEAR' gage is at 45 degrees;often called 'GAGE 2'.
3) The 'TRANSVERSE' gage is at 90 degrees;often called 'GAGE 3'.
4) If any stress exceeds yield, all calculated stresses in deeper increments are not valid and must not be used.
5) Angles are measured +ve counter-clockwise from the 'AXIAL' gage.

PICKERING MODERATER HEADER - RESIDUAL STRESS MEASUREMENTS
****

MEASUREMENT LOCATION:

LOCATION 44 - AFTER PROOF TESTING
(Refer to Figure 1)

DATE: 11/05/87
TIME: 09:05

ROSETTE TYPE:125-RE
YOUNG'S MODULUS: 30.0 Mpsi
POISSON'S RATIO:0.30
HOLE DEPTH INCREMENT:0.020in.
HOLE DIAMETER:0.117in.

PRINCIPAL STRESSES:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) SIGMA1	SIGMA2	PRINCIPAL ANGLE(DEG.)
0.000 - 0.020	-21	-21	-31	+29.6	+20.2	+112.0
0.020 - 0.039	-35	-37	-64	+22.7	+9.2	+109.0
0.039 - 0.059	-31	-40	-82	+5.3	-8.5	+95.0
0.059 - 0.079	-23	-39	-95	+7.0	-11.1	+98.0
AVERAGES:				+16.2	+2.5	+103.5

1 R= 3.4647283922

STRESSES IN GAGE DIRECTIONS:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) AXIAL	SHEAR	TRANS.
0.000 - 0.020	-21	-21	-31	+21.5	-3.3	+28.2
0.020 - 0.039	-35	-37	-64	+10.6	-4.1	+21.3
0.039 - 0.059	-31	-40	-82	-8.4	-1.2	+5.2
0.059 - 0.079	-23	-39	-95	-10.7	-2.5	+6.7
AVERAGES:				+3.3	-2.8	+15.4

NOTES:

1) The 'AXIAL' gage is at 0 degrees;often called 'GAGE 1'.
2) The 'SHEAR' gage is at 45 degrees;often called 'GAGE 2'.
3) The 'TRANSVERSE' gage is at 90 degrees;often called 'GAGE 3'.
4) If any stress exceeds yield, all calculated stresses in deeper increments are not valid and must not be used.
5) Angles are measured +ve counter-clockwise from the 'AXIAL' gage.

PICKERING MODERATER HEADER - RESIDUAL STRESS MEASUREMENTS

MEASUREMENT LOCATION:

LOCATION 4Z - AFTER PROOF TESTING
(Refer to Figure 1)

DATE: 11/05/87
TIME: 10:00

ROSETTE TYPE:125-RE
YOUNG'S MODULUS: 30.0 Mpsi
POISSON'S RATIO:0.30
HOLE DEPTH INCREMENT:0.020in.
HOLE DIAMETER:0.117in.

PRINCIPAL STRESSES:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) SIGMA1	SIGMA2	PRINCIPAL ANGLE(DEG.)
0.000 - 0.020	-11	-19	-7	+15.4	+1.8	+39.4
0.020 - 0.039	-22	-45	-16	+16.1	-1.0	+44.2
0.039 - 0.059	-31	-64	-24	+13.3	+3.5	+44.6
0.059 - 0.079	-36	-78	-27	+11.5	-3.8	+41.7
AVERAGES:				+14.1	+.1	+42.5

1 R= 3.4647283922

STRESSES IN GAGE DIRECTIONS:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) AXIAL	SHEAR	TRANS.
0.000 - 0.020	-11	-19	-7	+9.9	+6.7	+7.3
0.020 - 0.039	-22	-45	-16	+7.8	+8.5	+7.3
0.039 - 0.059	-31	-64	-24	+8.5	+4.9	+8.3
0.059 - 0.079	-36	-78	-27	+4.8	+7.6	+3.0
AVERAGES:				+7.8	+6.9	+6.5

NOTES:

1) The 'AXIAL' gage is at 0 degrees;often called 'GAGE 1'.
2) The 'SHEAR' gage is at 45 degrees;often called 'GAGE 2'.
3) The 'TRANSVERSE' gage is at 90 degrees;often called 'GAGE 3'.
4) If any stress exceeds yield, all calculated stresses in deeper increments are not valid and must not be used.
5) Angles are measured +ve counter-clockwise from the 'AXIAL' gage.

PICKERING MODERATER HEADER - RESIDUAL STRESS MEASUREMENTS

MEASUREMENT LOCATION:

LOCATION 43 - AFTER PROOF TESTING
(Refer to Figure 1)

DATE: 11/05/87
TIME: 10:45

ROSETTE TYPE:062-RE
YOUNG'S MODULUS: 30.0 Mpsi
POISSON'S RATIO:0.30
HOLE DEPTH INCREMENT:0.010in.
HOLE DIAMETER:0.065in.

PRINCIPAL STRESSES:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) SIGMA1	SIGMA2	PRINCIPAL ANGLE(DEG.)
0.000 - 0.010	-10	-106	-5	+59.7	-47.8	+44.3
0.010 - 0.020	-33	-108	+7	+24.1	-18.8	-32.3
0.020 - 0.030	-67	-125	+8	+29.0	+9.3	-13.4
0.030 - 0.039	-109	-142	+9	+55.5	+21.4	-10.6
AVERAGES:				+42.1	-9.0	-3.0

I R= 3.13475425961

STRESSES IN GAGE DIRECTIONS:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) AXIAL	SHEAR	TRANS.
0.000 - 0.010	-10	-106	-5	+7.2	+53.7	+4.5
0.010 - 0.020	-33	-108	+7	+11.8	-19.4	-6.6
0.020 - 0.030	-67	-125	+8	+28.0	-4.4	+10.4
0.030 - 0.039	-109	-142	+9	+54.4	-6.2	+22.6
AVERAGES:				+25.4	+5.9	+7.7

NOTES:

1) The 'AXIAL' gage is at degrees;often called 'GAGE 1'.
2) The 'SHEAR' gage is at 45 degrees;often called 'GAGE 2'.
3) The 'TRANSVERSE' gage is at 90 degrees;often called 'GAGE 3'.
4) If any stress exceeds yield, all calculated stresses in deeper increments are not valid and must not be used.
5) Angles are measured +ve counter-clockwise from the 'AXIAL' gage.

PICKERING MODERATER HEADER - RESIDUAL STRESS MEASUREMENTS

MEASUREMENT LOCATION:

LOCATION 9 - AFTER PROOF TESTING — DATE: 11/05/87
(Refer to Figure 1) — TIME: 10:25

ROSETTE TYPE:062-RE
YOUNG'S MODULUS: 30.0 Mpsi
POISSON'S RATIO:0.30
HOLE DEPTH INCREMENT:0.010in.
HOLE DIAMETER:0.066in.

PRINCIPAL STRESSES:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) SIGMA1	SIGMA2	PRINCIPAL ANGLE(DEG.)
0.000 - 0.010	-45	-36	-11	+30.7	+11.1	+12.6
0.010 - 0.020	-169	-126	-66	+83.9	+53.4	-2.5
0.020 - 0.030	-210	-162	-79	+7.6	-4.9	+32.2
0.030 - 0.039	-254	-177	-87	+52.5	+19.8	-22.7
AVERAGES:				+43.7	+19.8	+4.9

1 R= 3.06185299776

STRESSES IN GAGE DIRECTIONS:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) AXIAL	SHEAR	TRANS.
0.000 - 0.010	-45	-36	-11	+29.7	+4.2	+12.1
0.010 - 0.020	-169	-126	-66	+83.9	-1.3	+53.4
0.020 - 0.030	-210	-162	-79	+4.0	+5.6	-1.4
0.030 - 0.039	-254	-177	-87	+47.6	-11.6	+24.7
AVERAGES:				+41.3	-.8	+22.2

NOTES:

1) The 'AXIAL' gage is at 0 degrees;often called 'GAGE 1'.
2) The 'SHEAR' gage is at 45 degrees;often called 'GAGE 2'.
3) The 'TRANSVERSE' gage is at 90 degrees;often called 'GAGE 3'.
4) If any stress exceeds yield, all calculated stresses in deeper increments are not valid and must not be used.
5) Angles are measured +ve counter-clockwise from the 'AXIAL' gage.

PICKERING MODERATER HEADER - RESIDUAL STRESS MEASUREMENTS
****

MEASUREMENT LOCATION:

LOCATION 38 - AFTER PROOF TESTING
(Refer to Figure 1)

DATE: 11/05/87
TIME: 12:20

ROSETTE TYPE:062-RE
YOUNG'S MODULUS: 30.0 Mpsi
POISSON'S RATIO:0.30
HOLE DEPTH INCREMENT:0.010in.
HOLE DIAMETER:0.066in.

PRINCIPAL STRESSES:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) SIGMA1	SIGMA2	PRINCIPAL ANGLE(DEG.)
0.000 - 0.010	-38	-3	-54	+57.0	+11.6	+130.0
0.010 - 0.020	-72	-11	-114	+41.2	+12.2	+124.0
0.020 - 0.030	-115	-23	-139	+33.0	+13.2	-16.8
0.030 - 0.039	-152	-35	-173	+70.0	+41.6	-44.0
AVERAGES:				+50.3	+19.6	+48.3

I R= 3.06185299776

STRESSES IN GAGE DIRECTIONS:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) AXIAL	SHEAR	TRANS.
0.000 - 0.010	-38	-3	-54	+30.2	-22.4	+38.5
0.010 - 0.020	-72	-11	-114	+21.2	-13.4	+32.2
0.020 - 0.030	-115	-23	-139	+31.4	-5.5	+14.9
0.030 - 0.039	-152	-35	-173	+56.3	-14.2	+55.3
AVERAGES:				+34.8	-13.9	+35.2

NOTES:

1) The 'AXIAL' gage is at 0 degrees;often called 'GAGE 1'.
2) The 'SHEAR' gage is at 45 degrees;often called 'GAGE 2'.
3) The 'TRANSVERSE' gage is at 90 degrees;often called 'GAGE 3'.
4) If any stress exceeds yield, all calculated stresses in deeper increments are not valid and must not be used.
5) Angles are measured +ve counter-clockwise from the 'AXIAL' gage.

PICKERING MODERATER HEADER - RESIDUAL STRESS MEASUREMENTS

MEASUREMENT LOCATION:

LOCATION 33 - AFTER PROOF TESTING
(Refer to Figure 1)

DATE: 11/05/87
TIME: 13:25

ROSETTE TYPE:06Z-RE
YOUNG'S MODULUS: 30.0 Mpsi
POISSON'S RATIO:0.30
HOLE DEPTH INCREMENT:0.010in.
HOLE DIAMETER:0.065in.

PRINCIPAL STRESSES:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) SIGMA1	SIGMA2	PRINCIPAL ANGLE(DEG.)
0.000 - 0.010	-24	-22	-7	+18.0	+6.3	+18.7
0.010 - 0.020	-69	-53	-7	+26.8	+4.0	+8.7
0.020 - 0.030	-109	-80	-2	+25.8	+1.8	+11.8
0.030 - 0.039	-125	-97	+8	+6.4	-18.6	+29.2
AVERAGES:				+19.2	-1.6	+17.1

1 R= 3.13475425961

STRESSES IN GAGE DIRECTIONS:

DEPTH INC.(in.)	STRAINS AXIAL	SHEAR	TRANS.	STRESSES(ksi) AXIAL	SHEAR	TRANS.
0.000 - 0.010	-24	-22	-7	+16.8	+3.6	+7.5
0.010 - 0.020	-69	-53	-7	+26.3	+3.4	+4.6
0.020 - 0.030	-109	-80	-2	+24.8	+4.8	+2.8
0.030 - 0.039	-125	-97	+8	+.5	+10.6	-12.6
AVERAGES:				+17.1	+5.6	+.6

NOTES:

1) The 'AXIAL' gage is at 0 degrees;often called 'GAGE 1'.
2) The 'SHEAR' gage is at 45 degrees;often called 'GAGE 2'.
3) The 'TRANSVERSE' gage is at 90 degrees;often called 'GAGE 3'.
4) If any stress exceeds yield, all calculated stresses in deeper increments are not valid and must not be used.
5) Angles are measured +ve counter-clockwise from the 'AXIAL' gage.

APPENDIX C

Force/Moment Measurement Results

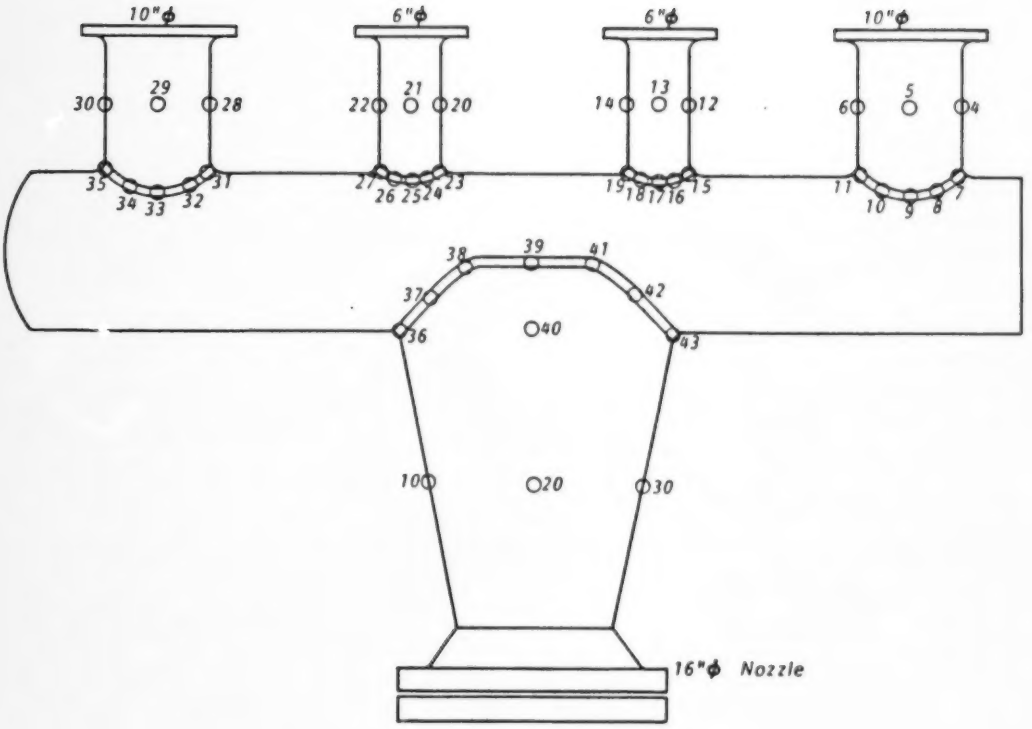
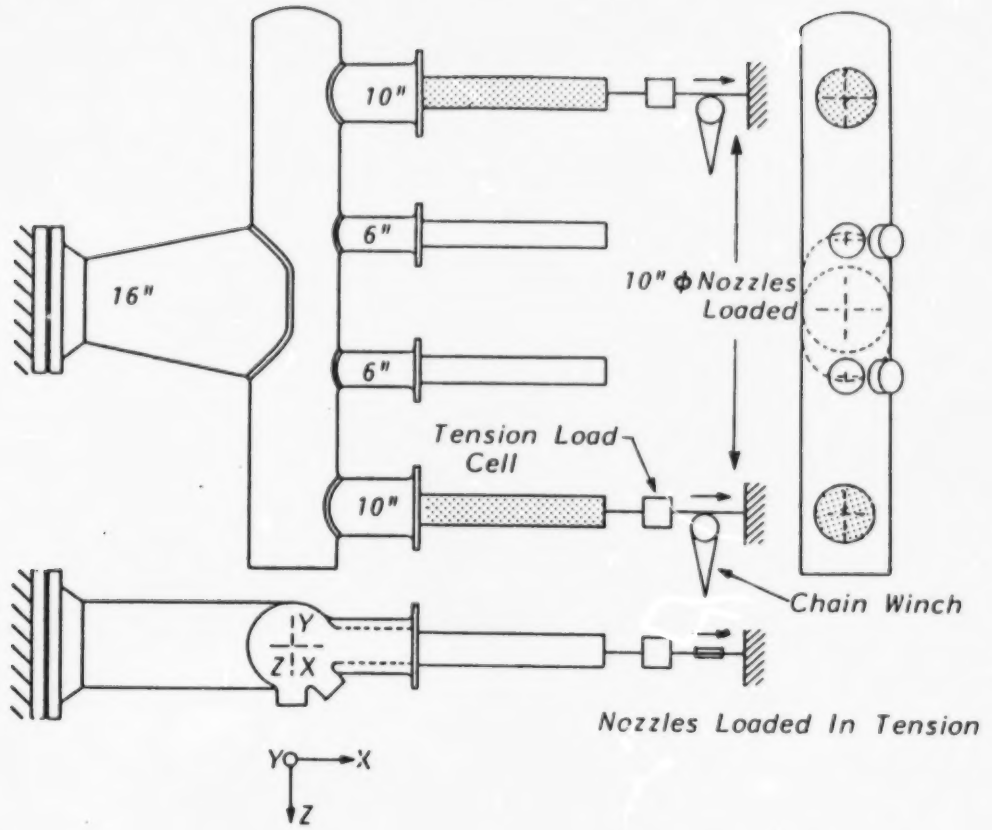


FIGURE C0

LOCATION OF STRAIN GAUGE ROSSETTES EMPLOYED DURING FORCE AND MOMENT MEASUREMENTS

174906-RD



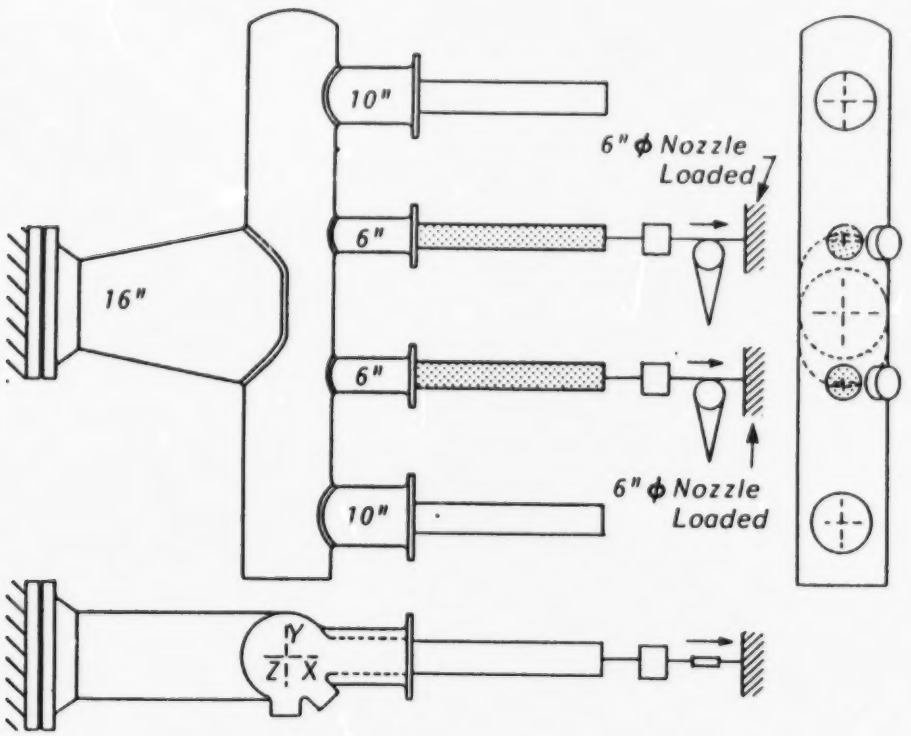


FIGURE C1

SCHEMATIC DIAGRAM OF X-AXIS FORCE TESTS

TABLE C1

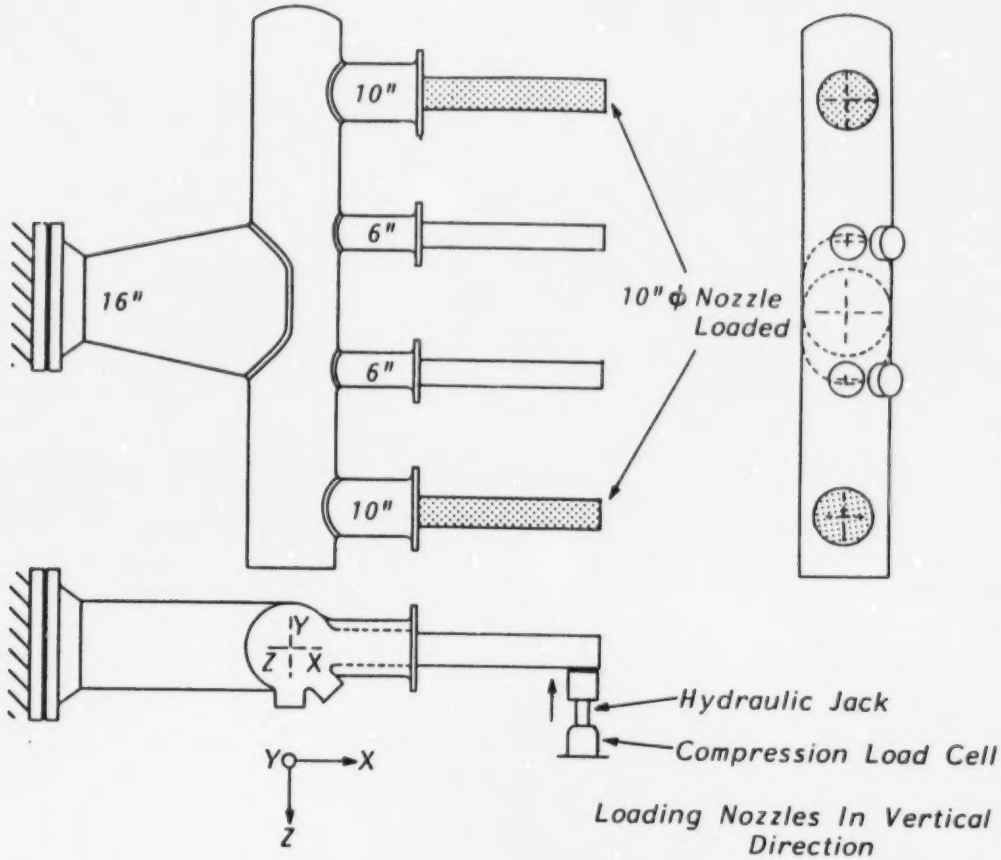
Selected Measurements For X-Axis Force Tests

Data Record Number	Channel # 156 (lbs)	Channel # 157 (lbs)	Rosette 7	Rosette 8	Rosette 9	Rosette 10	Rosette 11	Rosette 17	Rosette 25	Rosette 33	Rosette 39
6	567.5	570.3	450/80	730/520	2,300/980	830/-7	200/100	1,700/26	2,100/32	2,200/900	450/-230
8	1,045.6	1,063.3	700/0	1,300/770	3,690/1,600	1,200/-89	200/-200	3,470/41	4,000/200	3,360/1,300	680/-570
10	1,461.9	1,463.0	910/400	1,700/970	4,860/2,100	1,500/-170	200/-300	4,890/34	5,590/330	4,360/1,600	900/-820
12	2,001.9	2,012.8	1,200/500	2,300/1,300	6,360/2,700	1,800/-360	190/-490	6,900/64	7,740/540	5,700/2,000	1,200/-1,200
14	1,512.5	1,483.0	910/400	1,700/1,000	4,810/2,000	1,400/-180	200/-300	4,870/-25	5,880/410	4,610/1,700	930/-850
16	1,083.8	1,110.3	740/300	1,400/810	3,780/1,600	1,200/-100	200/-200	3,520/27	4,140/210	3,540/1,300	710/-560
18	525.6	547.5	430/0	730/520	2,200/930	800/-3	300/50	1,600/29	2,000/37	2,200/900	440/-210
20	2.5	32.0	200/-50	100/0	200/2	390/60	300/100	90/-350	-.6/-200	510/60	320/70

Results For 10" Diameter Nozzle Force Tests

Data Record Number	Channel # 156 (lbs)	Channel # 157 (lbs)	Rosette 9	Rosette 15	Rosette 16	Rosette 17	Rosette 18	Rosette 19	Rosette 25	Rosette 33	Rosette 39
24	496.3	473.8	550/100	890/780	2,900/1,000	12,600/5,200	1,900/600	300/100	6,910/3,200	780/100	-100/-810
26	1,029.4	1,045.0	1,100/400	1,700/1,700	4,880/2,000	17,600/7,400	3,150/800	500/300	11,900/5,400	1,100/200	0/-1,600
28	1,529.4	1,567.3	1,700/600	2,500/2,400	6,650/3,000	22,300/9,500	4,250/1,000	760/400	15,600/7,400	1,500/160	-800/-2,300
31	1,920.0	1,955.8	2,200/700	3,200/2,900	8,000/2,000	25,800/11,000	5,170/1,200	930/500	20,200/9,020	1,80/180	-1,000/-2,900
33	1,499.4	1,523.0	1,700/600	2,500/2,300	6,560/2,000	22,100/9,400	4,240/1,000	740/400	16,400/7,300	1,500/170	-800/-2,300
35	995.6	995.5	1,10/0	1,600/1,500	4,830/2,000	17,500/7,400	3,110/900	520/300	11,800/5,300	1,200/200	0/-1,600
37	504.4	510.8	630/90	930/820	3,190/1,000	13,200/5,500	2,100/700	350/100	7,300/3,200	760/100	-200/-860
39	3.8	34.5	250/-250	200/100	780/0	6,820/2,000	410/200	100/100	280/-50	330/-100	310/30

Results For 6" Diameter Nozzle Force Tests



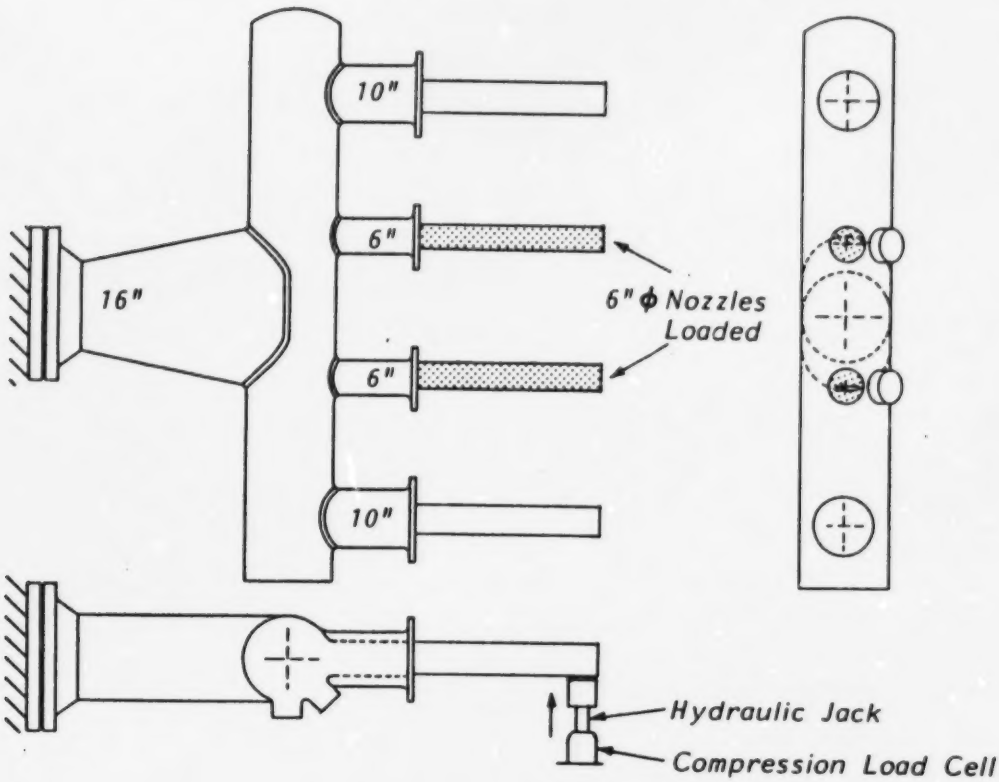


FIGURE C2

SCHEMATIC DIAGRAM OF Y-AXIS FORCE TESTS

TABLE C2

Selected Measurements For Y-Axis Force Tests

Data Record Number	Channel # 156 (lbs)	Channel # 157 (lbs)	Rosette 7	Rosette 8	Rosette 9	Rosette 10	Rosette 11	Rosette 17	Rosette 25	Rosette 33	Rosette 39
79	-266.2	-295.5	1,100/-860	-1,700/-3,100	-4,800/-9,100	-600/-1,600	560/200	33/1,000	320/-900	-6,200/-10,900	420/300
84	-526.2	-579.7	1,700/-1,600	-4,100/-6,310	-9,140/-17,300	-1,400/-3,310	670/-20	73/-1,400	1,000/-870	-11,200/-19,800	560/400
87	-255.6	-277.0	1,000/-820	-1,600/-2,900	-4,500/-8,580	-600/-1,500	610/200	43/-840	450/-710	-5,900/-10,400	410/300
92	-6.9	-14.5	460/-150	640/-190	1,000/-2,680	200/-100	620/400	-20/-330	200/-200	-830/-1,500	300/-30

Results for 10" Diameter Nozzle Force Tests

Data Record Number	Channel # 156 (lbs)	Channel # 157 (lbs)	Rosette 9	Rosette 15	Rosette 16	Rosette 17	Rosette 18	Rosette 19	Rosette 25	Rosette 33	Rosette 39
99	-127.5	-123.0	930/-2,500	43/-960	-2,600/-5,410	-8,310/-17,200	-2,400/-4,240	80/-730	-7,290/-14,700	-790/-1,600	7,800/700
102	-255.6	-243.5	640/-2,700	79/-1,800	-4,900/-10,400	-16,000/-32,910	-4,800/-8,240	1,600/-1,500	-14,000/-28,200	-1,200/-2,600	3,380/1,300
105	-178.1	-189.2	880/-2,500	27/-1,200	-3,300/-7,000	-10,600/-22,100	-3,100/-5,420	1,100/-940	-9,830/-19,900	-960/-2,000	2,300/900
111	-2.5	1.0	1,300/-2,200	0/-100	-200/-530	-700/-1,600	-100/-300	100/-30	0/-1,200	-300/-670	400/20

Results For 6" Diameter Nozzle Force Tests

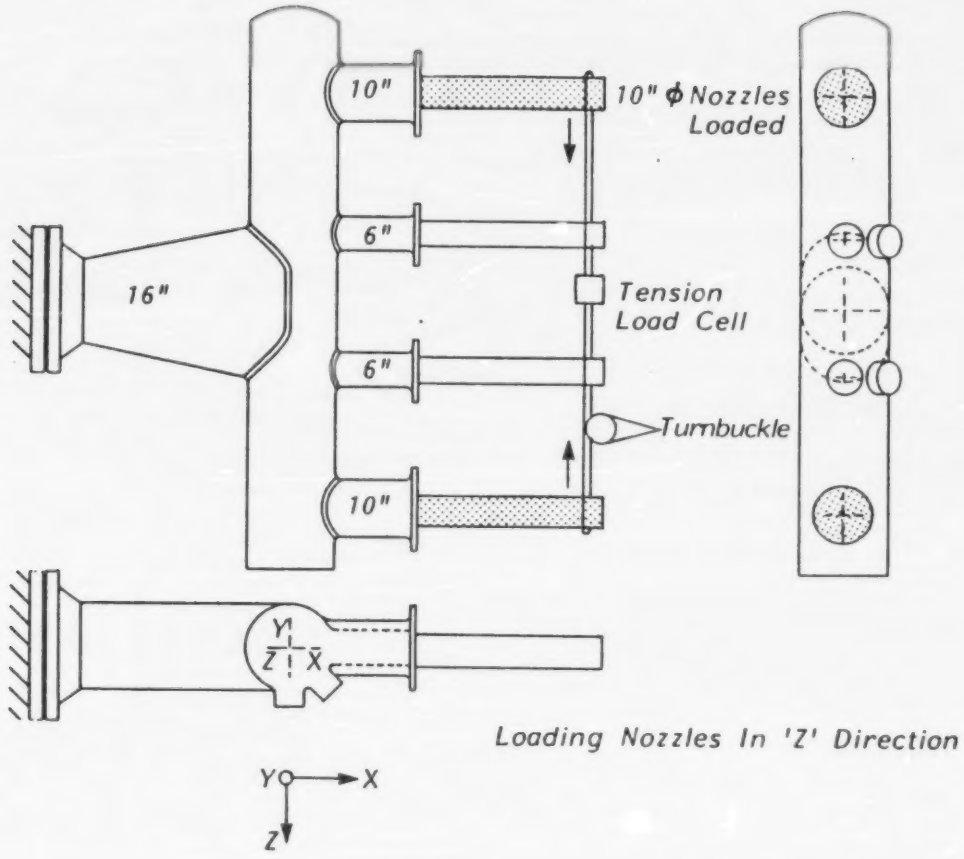


FIGURE C3

SCHEMATIC DIAGRAM OF Z-AXIS FORCE TESTS

TABLE C3

Selected Measurements For Z-Axis Force Tests

Data Record Number	Channel 0 156 (lbs)	Channel 0 157 (lbs)	Rosette 7	Rosette 8	Rosette 9	Rosette 10	Rosette 11	Rosette 17	Rosette 25	Rosette 33	Rosette 39
59	196.9	193.8	2,900/2,200	4,120/2,100	-910/-1,900	-2,200/-3,500	-2,300/-3,400	110/-800	-40/-800	-200/-1,200	530/80
63	612.5	609.3	8,640/6,970	13,400/6,830	-3,000/-6,020	-7,040/-11,100	-7,170/-10,700	380/-2,500	190/-2,400	-780/-3,820	1,600/200
65	815.0	798.3	11,400/9,310	18,000/9,160	-4,000/-8,030	-9,340/-14,700	-9,490/-14,200	550/-3,330	340/-3,120	-1,000/-5,120	2,100/250
68	605.0	597.3	8,580/7,140	13,800/6,900	-3,000/-6,010	-6,910/-11,000	-7,040/-10,500	480/-2,500	200/-2,400	-740/-3,830	1,600/200
72	193.8	198.0	3,000/2,700	5,460/2,500	-950/-1,900	-2,200/-3,650	-2,300/-3,300	230/-770	52/-780	-200/-1,300	590/100
74	-14.4	-15.7	380/-100	780/-63	0/-200	300/200	580/300	100/0	60/-150	-100/-200	100/80

Results for 10" Diameter Nozzle Force Tests

Data Record Number	Channel 0 156 (lbs)	Channel 0 157 (lbs)	Rosette 9	Rosette 15	Rosette 16	Rosette 17	Rosette 18	Rosette 19	Rosette 25	Rosette 33	Rosette 39
41	86.9	78.3	390/200	3,100/2,800	2,900/1,700	-1,500/-2,900	-2,500/-3,880	-3,700/-4,830	300/-200	440/300	540/0
43	173.8	161.8	760/400	6,660/5,710	6,090/3,400	-3,100/-6,160	-5,100/-7,930	-7,700/-10,100	470/-400	940/500	1,000/300
45	247.5	250.3	1,200/600	9,480/8,370	8,810/4,900	-4,800/-9,270	-7,740/-11,900	-11,400/-15,000	620/-660	1,200/600	1,500/300
47	337.5	344.0	1,600/810	13,100/11,600	12,000/6,710	-6,830/-13,300	-10,600/-16,200	-15,700/-20,600	650/-1,100	1,600/850	2,100/400
49	255.0	245.0	1,100/500	9,730/8,630	8,990/5,000	-5,000/-9,760	-7,810/-11,800	-11,600/-15,200	640/-760	1,200/600	1,600/300
51	164.4	170.5	770/300	6,630/5,930	6,320/3,400	-3,400/-6,640	-4,900/-7,820	-7,850/-10,200	590/-510	800/400	1,100/200
54	73.8	84.3	370/200	3,300/3,000	3,200/1,700	-1,700/-3,410	-2,100/-3,560	-3,800/-4,930	470/-340	460/200	590/100
56	-3.7	-4.5	30/0	200/100	380/50	0/-600	550/400	300/-40	200/-200	4/-100	200/30

Results For 6" Diameter Nozzle Force Tests

FIGURE 1

REMOVED UNIT 1 MODERATOR DISTRIBUTION HEADER AS
RELOCATED TO AUXILIARY IRRADIATED FUEL BAY

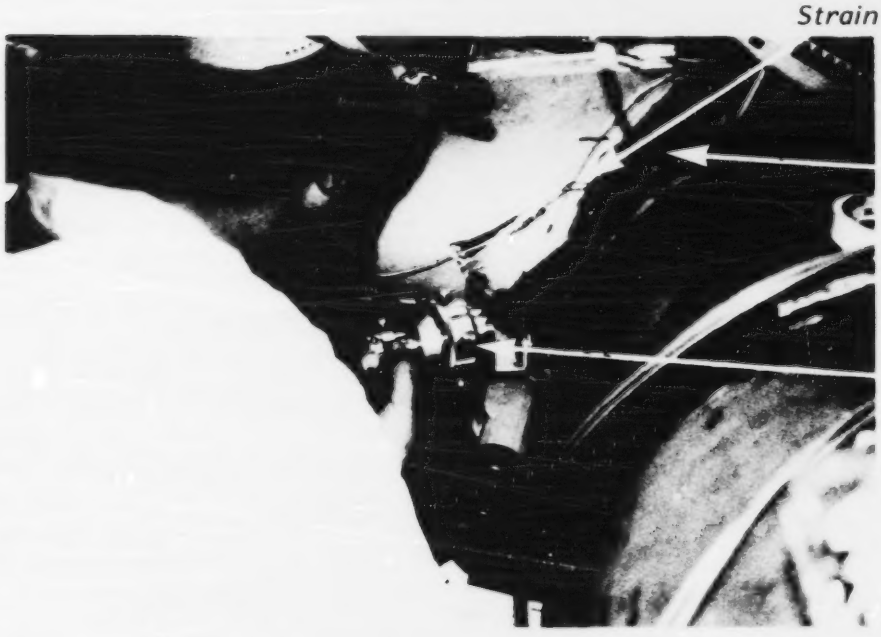


FIGURE 2

RESIDUAL STRESS MEASUREMENT BY THE HOLE-DRILLING METHOD
(At the Juncture of the 16 in Nozzle and the Main Header)

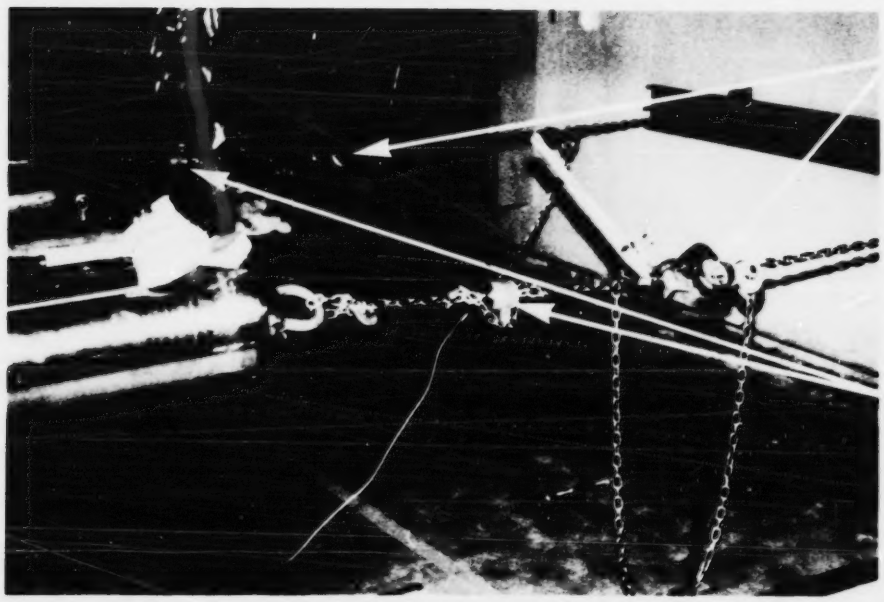


FIGURE 3

CONFIGURATION OF AXIAL FORCE TEST PROCEDURE
(SHOWN FOR 10" NOZZLES) USING CHAIN WINCHES

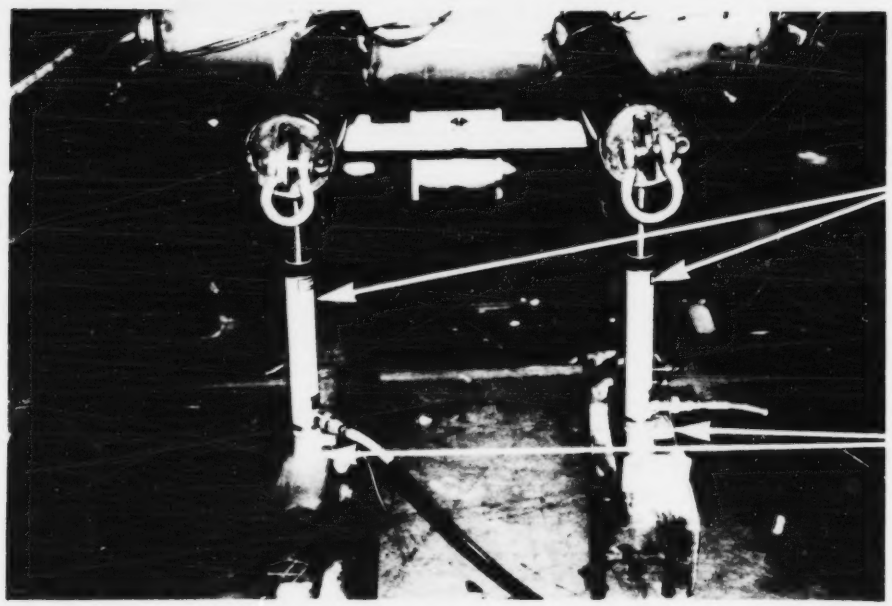


FIGURE 4

CONFIGURATION OF VERTICAL FORCE TEST PROCEDURE
(SHOWN FOR 6" NOZZLES) USING HYDRAULIC CYLINDERS

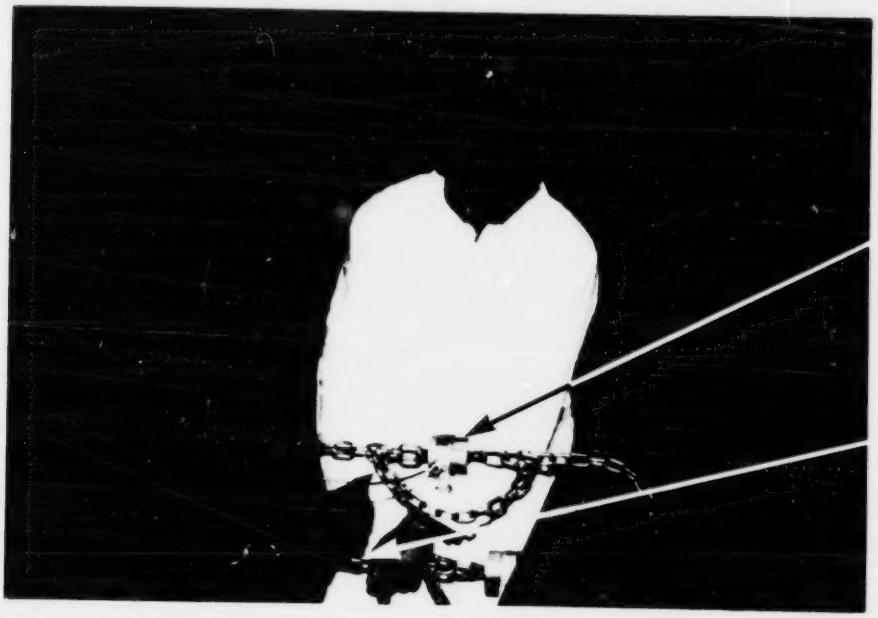


FIGURE 5

CONFIGURATION OF FORCE TEST PROCEDURE NORMAL TO NOZZLE AXES (SHOWN FOR 6" NOZZLES)

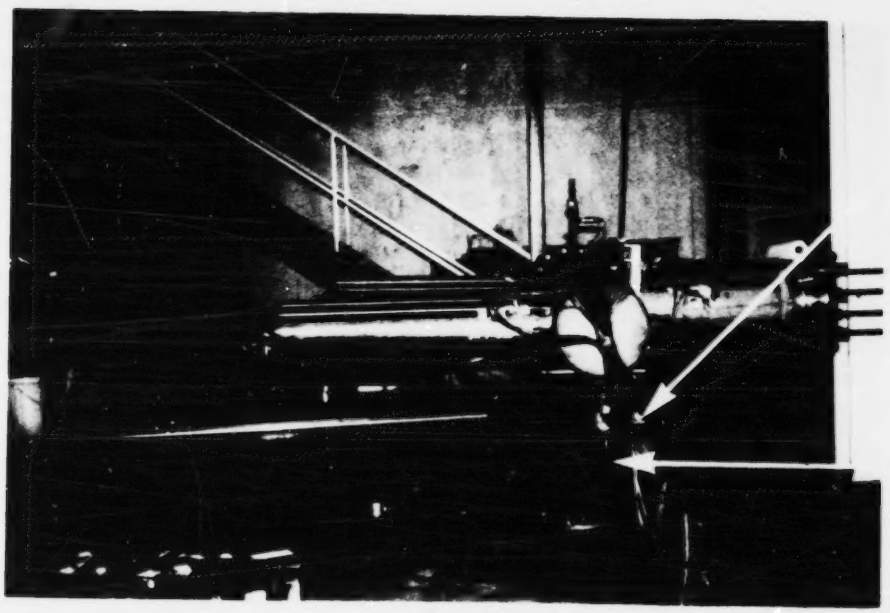

Strain Gauge, Pressure Transducers etc Wires from Header to Readout Instrumentation
Pressurization Hose From Header to Pump

FIGURE 6

VIEW OF INSTRUMENTED HEADER FOR PRESSURE TESTS

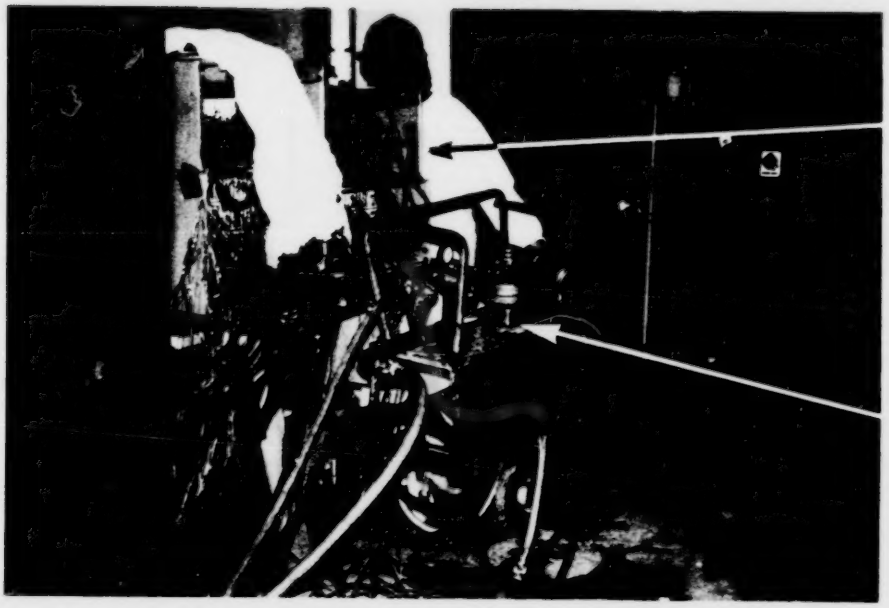


FIGURE 7

VIEW OF COMPRESSED AIR POWERED WATER PRESSURIZATION PUMP
(SHOWN ADJACENT TO THE READOUT LOCATION)

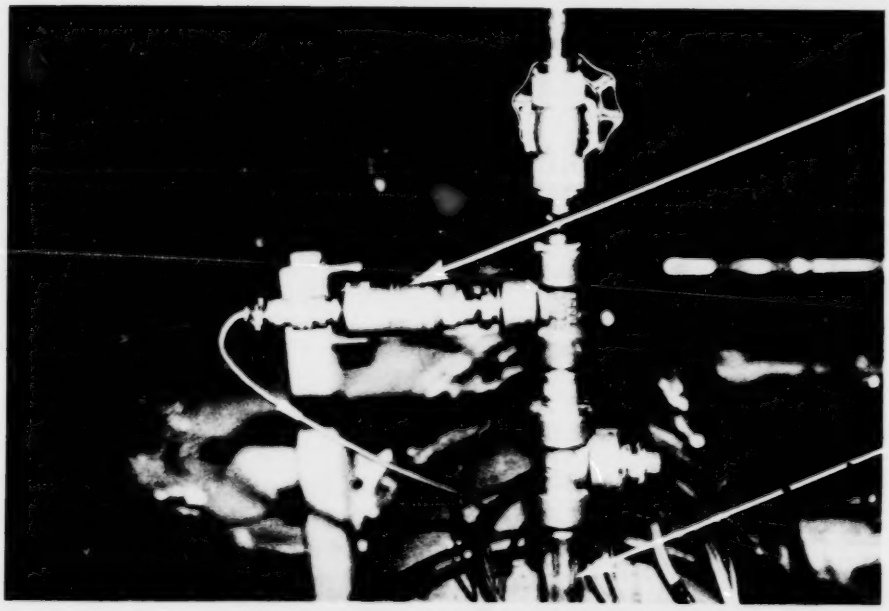


FIGURE 8

DETAILS OF PRESSURE TAP AND ELECTRONIC PRESSURE TRANSDUCER
(LOCATED ON TOP OF THE HEADER)

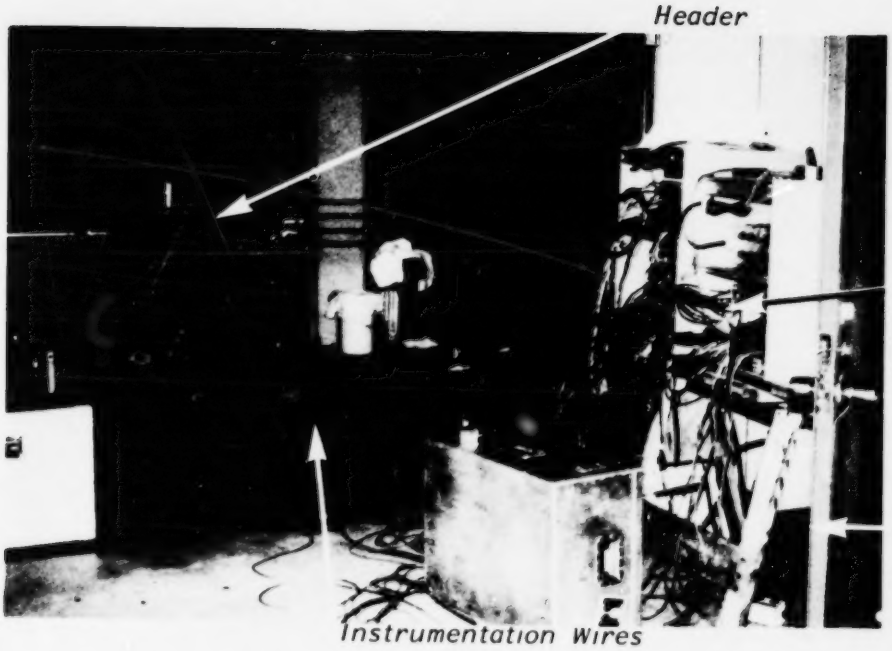


FIGURE 9
WIRING DETAILS OF MEASUREMENT INSTRUMENTATION

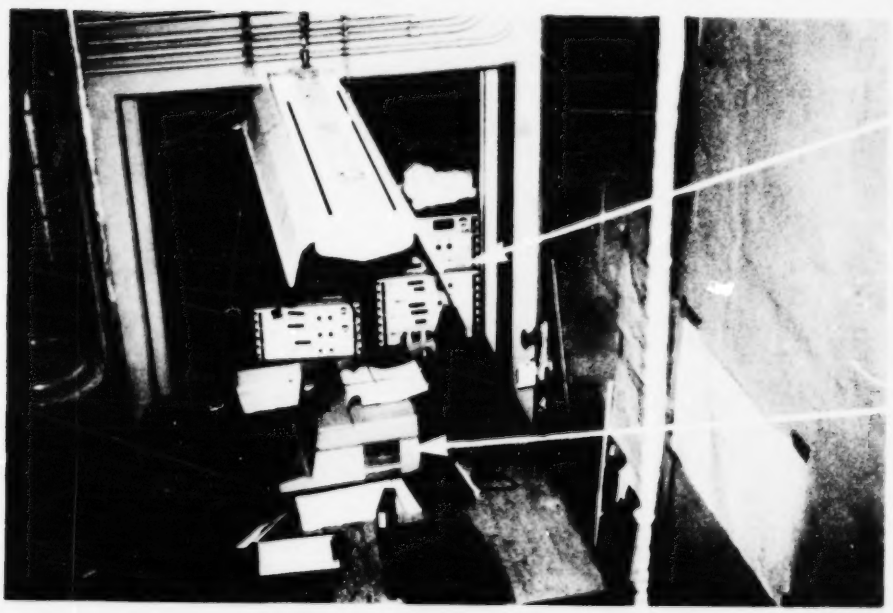


FIGURE 10
DATA ACQUISITION EQUIPMENT
(LOCATED IN PROTECTED AREA BEHIND CONCRETE WALL IN UNIT 1 AIFB)

174904-RD

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